The economic evaluation of a bicycle-sharing scheme for school and university destined commuter traffic in Stellenbosch, South Africa that is proposed as a sustainable mode of transport to relieve traffic congestion:

A case study for the R44 inbound traffic from Somerset West

by
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"Progress is impossible without change, and those who cannot change their minds cannot change anything."

- George Bernard Shaw

By submitting this research project electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the authorship owner thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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ABSTRACT

The traffic congestion problem in the university town of Stellenbosch, South Africa is felt by a prodigious share of its residents and commuters on a daily basis. A quantification of the status quo verified that there are simply too many vehicles on the extended Stellenbosch road network at specific hours of the day (i.e. the demand surpasses its capacity), and that long-term growth cannot be withstood. The greater part of intersections on the main roads operate at a Level of Service F, and in most instances, all probable alternative routes to a driver do not bestow any significant gain in terms of travel time and / or delay. The Stellenbosch Municipality is one of the fastest growing municipalities in the country, and peak-period traffic congestion will spread over a longer time span if capacity problems remain unresolved.

Within this context, this research project proposes bicycle-sharing as a congestion-relief measure that is believed to be 'smarter' and more sustainable than the standard roadway capacity expansion actions. This project is an economic evaluation of a theoretical bicycle-sharing scheme for school and university destined commuter traffic in the town of Stellenbosch, with the traffic congestion along the R44 from the Somerset West direction selected as the case study. By definition, bicycle-sharing is a non-motorised mode of transportation (NMT) for short-distance, point-to-point trips in which bicycles are made available to users on a 'sharing' basis. The Stellenbosch Municipality is making progress in the development of the NMT network in Stellenbosch, but whilst the efforts, no doubt, have the potential to reduce traffic congestion, they neglect the many road users with out-of-town origins and destinations. The results of an electronic questionnaire distributed to Stellenbosch school-learner parents and Stellenbosch University (SU) students and staff, in fact, revealed that the main barrier preventing these road users from making use of active transportation is that the travelling distance is too long. The proposed bicycle-sharing scheme, which is to be operated from Drop-and-Go zones (scholars) and Park-and-Rides (SU students and staff), extends NMT to these commuters.

The primary objective of this research was to evaluate the economic viability of the scheme. The secondary objectives were (1) to determine the first-order benefit and cost estimates of the scheme in the form of a Net Present Value, Benefit-Cost Ratio and First Year Rate of Return, and (2) to conceptually design a premier bicycle-sharing scheme for Stellenbosch and its school and university destined distance-travellers, so as to attain high, but still realistic, values for the economic parameters. The benefits were divided into direct benefits to the users, and indirect benefits to society and the authorities.

The research design comprised (1) survey-based research to identify the number of potential users per road-user group (scholars, SU students and SU staff) and their barriers to cycling, and (2) evaluative research to appraise the costs (capital, launch and implementation, as well as operating and maintenance costs), benefits (mobility, health, safety and environmental improvements) and revenue potential. The conceptual design for which the economic evaluations were performed, proposes an automatic system for which the smartphone is to be the key component. The bicycle-sharing alternative and a geometric-improvement alternative (capacity enhancement at the R44 / Van Reede intersection) were tested against the null alternative: a continuation of the existing conditions with no money invested for upgrades. Various scenarios were analysed for the bicycle-sharing alternative, relating to scheme size, ridership, fare structure and operational model modifications. A traffic demand model, i.e. a simulation, was created as part of the evaluative research (using self-conducted traffic volume counts as the input), which determined the vehicle miles travelled, vehicle hours

travelled and mean system speed for each alternative and scenario. These parameters served as the input to the vehicle-operating-cost, travel-time and CO_2-emission travel-cost (and eventual travel-cost-saving) equations. Probe data was used to calibrate the model.

For the three road-user groups scholars, SU students and SU staff, 358, 490 and 241 potential bicycle-users were identified according to specified criteria, respectively. On the whole, it can be confidently stated that bicycle-sharing is an economically viable affair for the study area. First year rates of return ranging from 0.23 to 0.88 were determined for the scheme that was believed to have a total service life of 15 years, and benefit-cost ratios between 1.38 and 9.98 were computed for the future bicycle-share users. Whilst the geometric-improvement alternative was found to be economically viable, many of the appraised bicycle-sharing scenarios were learnt to be more so. At a time and place where the resources for a state-of-the-art public transit system are absent, bicycle-sharing is hence considered to be the front-runner in terms of congestion-relief measures. Championing the scheme is vital for its success, and the importance of it may, by no means, be underestimated. Further research should look into the benefits that are achievable on other Stellenbosch arterials, and hence determine to which extent bicycle-sharing can relieve traffic congestion on the wider Stellenbosch road network.

OPSOMMING

Die verkeersopeenhopings-probleem in die universiteitsstad van Stellenbosch, Suid-Afrika is deur 'n ontsaglike deel van sy inwoners en pendelaars op 'n daaglikse basis ontmoet. 'n Kwantifisering van die status quo bewys dat daar net te veel voertuie op die verlengde Stellenbosch padnetwerk op spesifieke ure van die dag is (d.w.s. die vraag oortref die kapasiteit), en dat langtermyn-groei nie teëgestaan kan word nie. Die grootste deel van kruisings op die hoofpaaie werk op 'n diensvlak F, en in die meeste gevalle, skenk al waarskynlike alternatiewe roetes nie enige beduidende voordeling in terme van reistyd aan die bestuurders nie. Die Stellenbosch Munisipaliteit is een van die vinnigste groeiende munisipaliteite in die land, en spitstyd-verkeersopeenhopings gaan oor 'n langer tydperk versprei as kapasiteitprobleme onopgelos bly.

In hierdie konteks, stel hierdie navorsingsprojek "bicycle-sharing" voor as 'n verkeersopeenhoping-verligtingsmaatreël wat geglo 'slimmer' en meer volhoubaar is as die huidige en standaarde handelinge van padkapasiteitsuitbreiding. Hierdie projek is 'n ekonomiese evaluering van 'n teoretiese "bicycle-sharing" skema bestem vir die skool- en universiteitpendelaarverkeer in die dorp van Stellenbosch, met die verkeersopeenhopings op die R44 van die Somerset-Wes rigting gekies as die gevallestudie. Per definisie is "bicycle-sharing" 'n nie-gemotoriseerde modus van vervoer (NGV) vir kortafstand, punt-tot-punt reise waarop fietse op 'n 'deel'-basis beskikbaar gestel word aan die gebruikers. Die Stellenbosch Munisipaliteit maak goeie vordering in die ontwikkeling van die NGV-netwerk in Stellenbosch, maar terwyl die pogings, geen twyfel, die potensiaal het om verkeersopeenhopings te verminder, verwaarloos hulle die talle padgebruikers met buite-dorp oorspronge en bestemmings. Die resultate van 'n elektroniese vraelys wat aan die Stellenbosch skoolleerder ouers en die Universiteit Stellenbosch (US) studente en personeel uitgestuur is, het aan die lig gebring dat lang afstande die oorheersende hindernis van aktiewevervoer is. Die voorgestelde "bicycle-sharing" skema, wat veronderstel is om van "Drop-and-Gos (skoliere) en "Park-and-Rides" (US-studente en personeel) te opereer, strek NGV na hierdie pendelaars.

Die primêre doel van hierdie navorsing was om die ekonomiese lewensvatbaarheid van die skema te evalueer. Die sekondêre doelwitte was (1) om die eerste-orde voordeel en koste ramings van die skema in die vorm van 'n nettohuidigewaarde, voordeelkosteverhouding en eerstejaaropbrengskoers te bepaal, en (2) om 'n "bicycle-sharing" skema uit die boonste rake vir die Stellenbosch en sy skool- en universiteitspendelaars te ontwerp, om hoë, maar nog steeds realistiese, waardes vir hierdie ekonomiese parameters te bereik. Die voordele is verdeel in direkte voordele vir die gebruikers en indirekte voordele vir die owerhede.

Die navorsingsontwerp het bestaan uit (1) opname-navorsing om die aantal potensiële gebruikers per padgebruiker groep (skoliere, US-studente en US-personeel) en hul hindernisse tot fietsry te identifiseer, en (2) evaluerende-navorsing om die koste (kapitaal-, implementerings-, asook bedryfs- en onderhoudskoste), voordele (mobiliteits-, gesondheids-, veiligheids- en omgewingsverbeteringe) en potensiële inkomste te evalueer. Die konseptuele ontwerp van die skema stel 'n outomatiese stelsel voor waarvoor die slimfoon 'n belangrike komponent behoort te wees. Die "bicycle-sharing"-alternatief en 'n kapasiteitsverbetering-alternatief (R44 / Van Reede kruising) is getoets teen voortsetting van die bestaande toestande met geen geld belê vir die opgradering. Verskillende opsies is ontleed vir die "bicycle-sharing"-alternatief, met betrekking tot veranderinge van die grootte van die skema, aantal ritte, tariefstruktuur en operasionelemodel. 'n Aanvraagmodel is geskep as deel van die evaluerende navorsing (met selfgetelde verkeer volume gebruik as die insette), wat die totale netwerk-reisafstand,

netwerk-ure van reis en gemiddelde netwerkspoed vir elke alternatief en opsie behaal het. Hierdie parameters het gedien as die insette vir die vergelykings van padgebruiker-, reistyd- en koolstofdioksiedemissie-koste (en uiteindelike besparingskoste).

Vir die drie padgebruikers skoliere, US-studente en US-personeel, is, onderskeidelik, 358, 490 en 241 potensiële fiets-gebruikers geïdentifiseer (volgens gespesifiseerde kriteria). Op die geheel, kan dit met selfvertroue verklaar word dat “bicycle-sharing” vir die studie area ekonomies lewensvatbaar is. Eerstejaaropbrengskoerse wat tussen 0,23 en 0,88 wissel is bepaal vir die skema wat 'n totale diens lewe van 15 jaar het, en voordeelkosteverhoudings tussen 1,38 en 9,98 is gevind vir die toekomstige “bicycle-sharing”-gebruikers. Terwyl die kapasiteitsverbeterings-alternatief ekonomies lewensvatbaar gevind is, is baie van die gewaardeerde “bicycle-sharing” opsies meer so. Op 'n tyd en plek waar die hulpbronne vir 'n gesofistikeerde openbarevervoerstelsel afwesig is, is “bicycle-sharing” vandaar beskou as die voorloper in terme van die verkeersopeenhoping-verligtingsmaatreëls. Bevordering van die skema is die sleutel tot sy sukses, en die belangrikheid daarvan mag deur geen manier onderskat word nie. Verdere navorsing kan kyk na die voordele wat bereikbaar is op ander Stellenbosch hoofverkeerspaaie, en dus bepaal tot watter mate “bicycle-sharing” verkeersopeenhopings op die breër Stellenbosch padnetwerk kan verlig.

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LIST OF PUBLICATIONS

A component of this research project has been published and was presented as part of the 1st International Conference on **The Use of Mobile Information and Communications Technology in Africa** (UMICTA 2014), held in Stellenbosch in December 2014. This conference forms part of an ongoing collaboration effort between the department of Electrical and Electronic Engineering at Stellenbosch University and the College of Computing and Information Sciences at Makerere University. A paper titled "*A Quantitative Measure of Congestion in Stellenbosch using Probe Data*" was submitted for the conference. A summary of this paper is provided as part of the status quo of Stellenbosch traffic congestion in ***Section 1.1.3.1***.

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AADT	Average Annual Daily Traffic
Ave	Avenue
BCR	Benefit-Cost Ratio
BoQ	Bill of Quantities
BPR	Bureau of Public Roads
BRT	Bus Rapid Transit
CBA	Cost / Benefit Analysis
CBD	Central Business District
CAPEX	Capital Expenditure
CoCT	City of Cape Town
COSATU	Congress of South African Trade Unions
CWDM	Cape Winelands District Municipality
FCD	Floating Car Data
GDP	Gross Domestic Product
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSM	Global System for Mobile Communication
GTZ	German Technological Cooperation
h	hour/s
HCM	Highway Capacity Manual
HGV	Heavy Goods Vehicle
HV	Heavy Vehicle
HSM	Highway Safety Manual
ICA	Intersection Capacity Analysis
ICT	Information and Communication Technology
IRT	Integrated Rapid Transit
IT	Information Technology
ITS	Intelligent Transport Systems
km	kilometre/s
km/h	kilometre/s per hour
KMZ	Keyhole Markup Language Zipped
LOS	Level of Service
m	metre/s
min	minute/s
NMT	Non-Motorised Transport

no.	number
NPV	Net Present Value
OSM	OpenStreetMap
PCE	Passenger Car Equivalent
PPA	Pedal Power Association
PrT	Private Transport
PTZ	Pan Tilt Zoom
PWOB	Present Worth of Benefits
PWOC	Present Worth of Costs
QR	Quick Response
REC	Research Ethics Committee
Rd	Road
s	seconds
SSML	Stellenbosch Smart Mobility Laboratory
St	Street
SU	Stellenbosch University
TDM	Travel Demand Management
TPB	Theory of Planned Behaviour
UN	United Nations
VAT	Value Added Tax
VD	volume-delay
VOC	Vehicle Operating Cost
VOT	Value of Time
WHO	World Health Organization

1 INTRODUCTION AND BACKGROUND TO THE PROBLEM

As the research title imparts, this project is an economic evaluation of a theoretical bicycle-sharing scheme for school and university destined commuter traffic in the town of Stellenbosch that is to be implemented as a sustainable mode of transportation to relieve traffic congestion. This introductory chapter, along with ***Chapter 2***, serves to provide the knowledge base required to understand the gist and the significance of the research. The chapters, in other words, provide the wheels on which the rest of this document rides. In this chapter, the definition of bicycle-sharing is given, after which the environment into which the scheme is to be implemented, namely the town of Stellenbosch, is introduced. This introduction includes the results of an analysis of the status quo of the Stellenbosch traffic congestion. Since the focal objective of the theoretical bicycle-sharing scheme is to relieve traffic congestion, these results formed the foundation, and ultimately the point of departure, of this research project. Alternative congestion relief measures are furthermore presented in this chapter, but in due course the attention is drawn to the need for Non-Motorised Transport (NMT), and existing NMT plans for Stellenbosch are shared. The final subsection provides a description of the research, including the research statement, research objectives and an outline of the chapters that follow.

1.1 BACKGROUND

1.1.1 WHAT IS BICYCLE-SHARING?

Many other popular terms are used to describe bicycle-sharing schemes, e.g. public bicycle systems / programmes, bike share schemes and smart bike systems. These systems are a transportation service, more specifically smart mobility service, in which bicycles are made available to users on an as-needed 'sharing' basis without the costs and responsibilities of bicycle ownership (Shaheen *et al*., 2010). Two bicycle-sharing models exist, namely the community bicycle-sharing model and the residential bicycle-sharing model (Gifford & Campus, 2004). In the first model, the user checks out a bicycle from any self-service bicycle station and returns it to any other bicycle station within the system's service area. In the second model, the bicycle is returned to the station where it was checked out. The trips are mainly of a short-distance and spontaneous nature, and are often combined with other transportation modes. Bicycle-sharing schemes are a transport intervention aimed at reducing congestion and improving the modal share of bicycles; they are usually for commuting and not for leisure-orientated mobility, as is the case with traditional bicycle rentals that are mostly established in areas with a high tourist concentration. A more detailed overview of bicycle-sharing schemes is given in ***Section 2.4***.

1.1.2 BACKGROUND TO THE TOWN OF STELLENBOSCH

The historical town of Stellenbosch, located approximately 50 km east of Cape Town, is regarded as the core regional settlement of the Stellenbosch Municipality, set in the Western Cape of South Africa (see ***Figure 1.1***), which, moreover, governs the towns of Franschhoek, Pniel and neighbouring rural

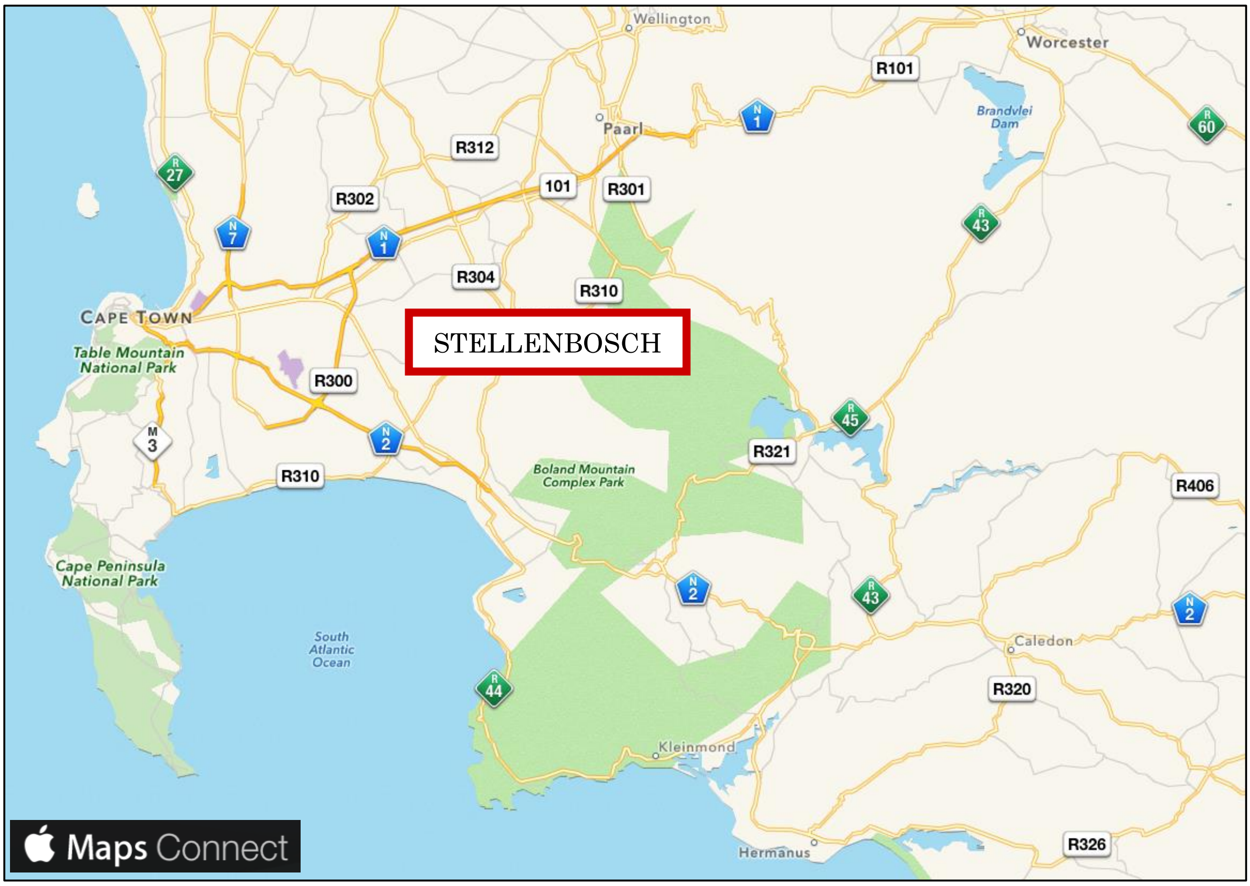


Figure 1.1: Location of Stellenbosch within the Western Cape, South Africa.

areas. Surrounded by the mountainous Cape Winelands region, the Stellenbosch valley itself is comparatively flat at an average elevation of 136 m above sea level. Stellenbosch is the second oldest town in South Africa and is alternatively referred to as 'Eikestad' (the city of oaks). The abundance of oak trees planted by the town's founder, Simon van der Stel, along with Cape Dutch, Georgian and Victorian architectural facades, enhance its prominent aesthetic value. The region's renowned wine industry and favourable Mediterranean climate likewise attract many international tourists. Stellenbosch also has highly desirable upmarket residential areas, and is a popular place for business headquarters.

According to the national census, the municipality had a population of 155,733 inhabitants in 2011 (growth rate of 2.75 from 2001) and a population density of 187 persons/km^2. Excluding the populations of the outlying towns and suburbs of De Hollandsche, Elsenburg, Franschhoek, Jamestown, Klapmuts, Koelenhof, Kylemore, Lanquedoc, Lynedoch, Pniel, Raithby, Robertsvlei and Wiesiesdraai, a population of 113,051 remained for the Stellenbosch area. Of the 43,420 households, 2,805 are agricultural households and 75.1% are formal dwellings. The general unemployment rate is 15.2%. (Statistics South Africa, 2011). Applying the growth rate of 2.75, the 2015 municipality population would be around 173,600 and the Stellenbosch town population 126,000.

Stellenbosch has highly respectable educational institutions. It is home to the Stellenbosch University (SU), which in 2014 had 24,805 enrolled students on the Stellenbosch campus and a total personnel size of 3,103 members (Stellenbosch University, 2014). One third of these students reside in or near the core campus; another third reside in the town or the immediate surrounding area; and the final third reside in the neighbouring towns or the Cape Metro (Vela VKE Engineers, 2011). Moreover, twenty-seven schools are located in Stellenbosch, spread across the various suburbs and the informal settlement Kayamandi. Eight of these schools are high schools, attracting and accommodating learners from neighbouring towns and even other parts of the country.

The town's transportation system is dominated by private motorisation (i.e. light motor vehicles) – a problem arising from the conventional transportation paradigm that traditionally prioritised the mobility of the private motor vehicle. Stellenbosch has a surfaced road network of 235,777 m, and 0.9 light motor vehicles per household, as per a household survey conducted in 2008 (Vela VKE Engineers, 2011). Apart from the school buses, the town has no formalised bus services to offer, and minibus taxis accommodate mainly low-income residents and farm workers. Furthermore, the middle and upper class have a negative perception of the rail system, believing it to be of poor quality, unreliable and a concern for safety and security.

1.1.3 STATUS QUO OF STELLENBOSCH TRAFFIC CONGESTION

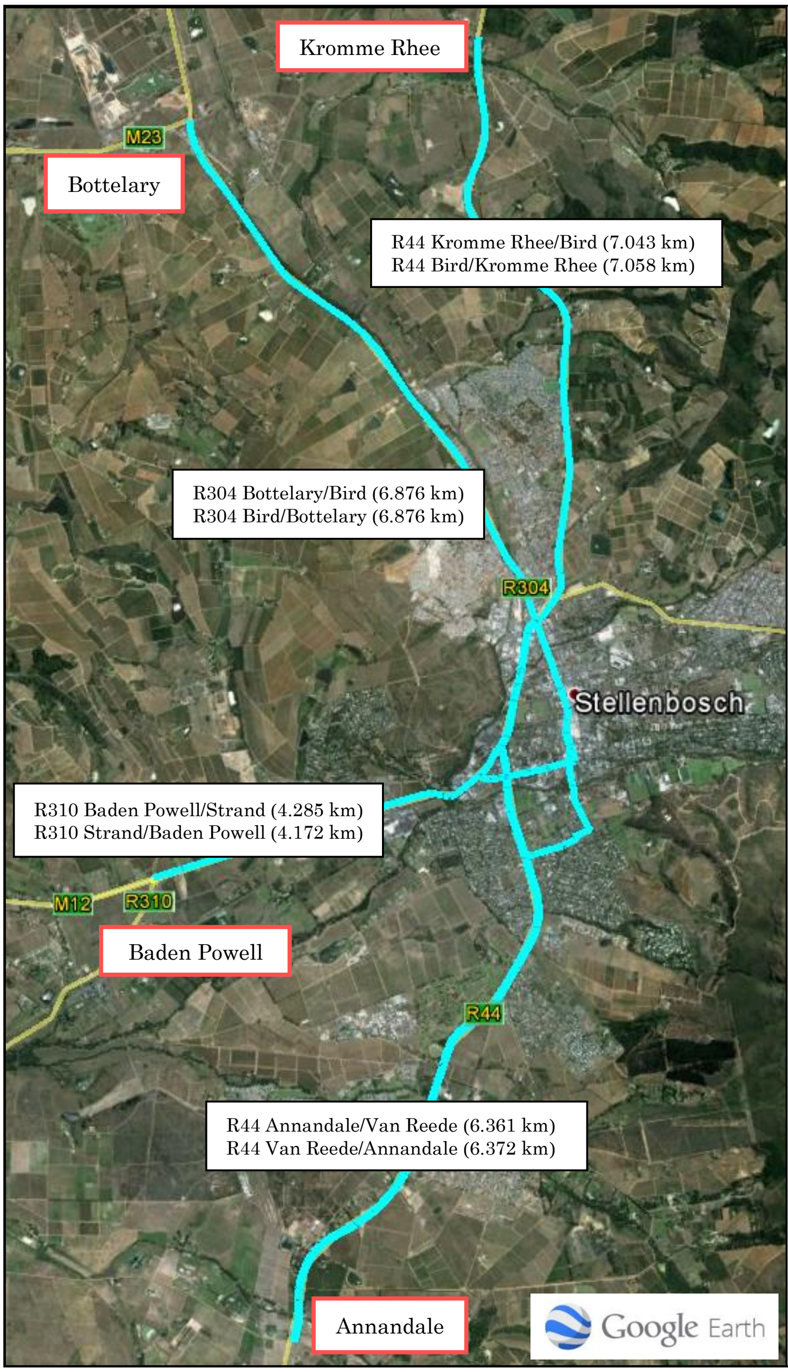
The level of prevailing Stellenbosch traffic congestion, as well as its growth over time, has been studied by numerous independent studies conducted in various manners. Studies conducted by the author made use of probe data and feedback from electronic questionnaires completed by parents of several schools in Stellenbosch, as well as SU students and staff. As very few investigations have been undertaken to quantify the level of congestion in Stellenbosch beyond traffic volume counts, time was spent on this quantification to attain a full understanding of the scope of the problem before beginning to address (by looking at the role bicycle-sharing could play in improving this level of congestion). The findings were assessed against the findings of research performed by and for the Stellenbosch Municipality. The studies found the complaints and frustration of the Stellenbosch residents to be valid; the traffic congestion is both unacceptable at present and unsustainable for the future. The individual techniques and results of the studies are further described in the subsequent subsections.

1.1.3.1 PROBE DATA

The growth of traffic congestion in Stellenbosch over the years 2011 to 2014 was studied by the author by means of historic probe data, made available through the TomTom Stats Portal – a self-service web portal solution delivered in the cloud. Probe data is information amassed while monitoring a sample of transportation-system users as they pass predefined points along a segment of thoroughfare. A more detailed description of TomTom's data processing methodology is given in ***Section 4.2.3.2***. TomTom is a partner of the Stellenbosch Smart Mobility Laboratory (SSML) in which the author works. For this reason specifically TomTom probe data was used in this research project, but of course other providers of probe data also exist.

The analysis encompassed the four major arterials leading into and out of Stellenbosch, and some of the central roads linked to these arterials that are observed to be exceptionally congested. The latter routes are also those most utilised by vehicle trips with an origin or destination in the suburb Krigeville (location of five schools). The significance of this is discussed in ***Section 1.3***. All probed routes are shown in ***Figure 1.2***. The analysis does not illustrate the full picture of congestion in Stellenbosch, but it is indicative enough to draw some conclusions.

To acquire a general overview of the traffic congestion level in Stellenbosch, the peak-hour delay (a straightforward and easily-understood measure of traffic congestion) was computed for each route and



TOWN CENTRE:
Adam Tas/Piet Retief via Dorp (1.032 km)
Piet Retief/Adam Tas via Dorp (1.032 km)
Bird/Van Reede via Piet Retief (3.303 km)
Van Reede Bird via Piet Retief (3.250 km)
Bird/Van Reede via R44 (2.715 km)
Van Reede/Bird via R44 (2.735 km)

Figure 1.2: Map of studied routes in Stellenbosch using probe data.

for each analysed year from the obtained outputs. Delay is here defined as the difference between the actual travel time and free-flow travel time. More complex and scientifically significant traffic congestion indices and measures were also applied. These are:

1. speed reduction index;
2. congestion index;
3. travel rate;
4. delay rate;
5. relative delay rate; and
6. delay ratio.

All congestion measures are based on an average day (Tuesday to Thursday, for the months February to March).

The speed reduction index reflects the ratio of the relative speed change between congested and free-flow conditions. Congestion usually occurs when the index exceeds 4 to 5 (Lomax *et al*., 1997). The congestion index was developed by D'Este *et al*. and Taylor (Hamad & Kikuchi, 2002). A value of 0 indicates a very low level of congestion, as the travel condition is close to the free-flow condition in this case; a value greater than 2 corresponds to a very congested condition (Hamad & Kikuchi). Travel rate is the rate of motion, in min/km, for a specified roadway segment or trip. It is the inverse of speed and is computed by dividing the segment travel time (min) by the segment length (km). Delay rate is the rate of time loss for vehicles operating in congested conditions, in min/km, for a specified roadway segment or trip. It is calculated as the difference between the actual travel rate and the acceptable travel rate. Literature suggests that acceptable congestion standards may be related to the congestion perceived by travellers. Motorists are usually aware of congestion when travel speeds reduce to 60 to 70% of the free-flow speeds (Lomax *et al*.). This theory was adopted, applying a congestion awareness at 70%. Relative delay rate is a dimensionless measure that is used here to compare the relative congestion on the various selected routes. It is calculated as the delay rate divided by the acceptable travel rate. Delay ratio is a dimensionless measure also used to compare the relative congestion levels on the various selected routes. It is calculated as the delay rate divided by the actual travel rate.

The full set of results of the applied traffic congestion measures as presented in ***Appendix B.1, Table B.1***, together with their respective formulas. The complete probe data output files for the specified routes are provided on the attached CD. The greater the value, the more severe the congestion. Negative values result when the actual travel conditions outshine the acceptable travel conditions. After computing the arterial speed reduction and congestion indices, it was apparent that the outbound and inbound arterials experience little congestion in the morning and afternoon, respectively. The remaining traffic congestion measures were thus not applied to these routes. The results of route Van Reede/Bird via Piet Retief for 2014 are typed in bold and italics, as there is indubitably an error in the obtained free-flow data. The sample size was less than 10 in this case, which conceivably explains this error. A summary of the results is given in the following subsections.

1.1.3.1.1 STELLENBOSCH ARTERIALS

The growth of traffic congestion (since 2011) is inconsistent, but present. On the inbound arterials, typical, daily-based peak delay (occurring in the morning) is 6.5 to 12 minutes, with an average of 9 minutes. This has increased from 4 to 8 minutes for the years 2011 and 2012. Inbound delay is especially bad on the R304, where the average peak delay is 12 minutes. 15% of commuters encounter delays of 16 minutes or more, however. The average peak-hour speed on this route is 21 km/h opposed to 56 km/h during free-flow. In the past, the inbound peak delay on the R44 from Somerset West was the worst, but it has interestingly remained constant at an average of approximately 8 minutes in the peak hour since 2011. From 2013 to 2014, inbound peak delay on the R44 from Paarl increased by an extraordinary 60% to 10 minutes, making it the most congested inbound arterial in the morning for 2014. The other congestion measures also denote the significant growth in traffic congestion on this inbound arterial. Inbound peak delay on the R310 has increased gradually to 6 minutes, making it the arterial with the least unfavourable conditions. If these values do not strike any alarm bells yet, it must be remembered that the delays experienced in town must still be added to these values (see ***Section 1.1.3.1.2)***, and that Stellenbosch is also not a metropolis in which considerable peak-hour delays can always be expected.

In terms of the speed reduction index, all morning inbound-values have been above 4 since 2011. In 2014, they were all around 6 with the exception of the R310 Strand / Baden Powell Route. There was a construction / maintenance zone on this route at the time, which influenced the data. The congestion index of the inbound arterials in the mornings lay between 1.6 and 1.9 for 2014 (excluding the R310). This is an increase from 2011, where the values lay between 0.7 and 1.4.

Although an increase in the typical outbound peak arterial-delay (occurring in the afternoon) is evident, the delay is minimal compared to inbound peak delay. It is under 5 minutes in all but one case; outbound peak delays on the R304 have close to doubled since 2013 to 6.3 minutes.

1.1.3.1.2 CENTRAL ROADS

In-town analyses were performed along the R44 (Strand Rd and Adam Tas Rd), in Dorp St and along Bird St to and from the R44 / Van Reede Rd intersection via Mill St and Piet Retief St (both directions). To travel from the R44 / Van Reede Rd intersection to the R44 / Bird St intersection, and vice versa, is always quickest along the R44. This route is not only shorter in travel time and distance, but its average peak delay of 6.5 minutes is less than that of 8 to 9 minutes along Bird St, Mill St and Piet Retief St. In fact, vast improvements were observed along the R44. The peak morning-delay from the R44 / Van Reede Rd intersection to R44 / Bird St intersection of almost 5 minutes in 2014, was 7.9 minutes less than that of 2013. The peak hour shifted to the afternoon in 2014, but this delay is still a minute less than the afternoon-peak delay of 2013. The opposite direction's peak delay, which has been in the afternoon since 2011, halved gradually between 2011 and 2013, and has remained constant since. The improvements of traffic congestion along the R44 are most likely not explained by fewer motor vehicles traversing the road section, but rather by efficiency improvements of the traffic control. This route nevertheless remains amongst the most congested routes in Stellenbosch.

The peak delay on the other considered routes has increased only slightly since 2013 and lies between 8 and 9.3 minutes for Bird St, Mill St and Piet Retief St and between 2.5 and 5 minutes for Dorp St. The short delays on Dorp St are misleading, however. In 2014, it was in fact the road with the highest travel rate (slowest average travel speeds). This congestion measure takes the length of the route into account, and thus gives a clearer picture. In general, Dorp St (Piet Retief St to Adam Tas Rd) has the most severe peak-hour congestion of all the studied routes. There are no other routes for its users, as all alternatives in some way lead to those routes next on the list of the most congested routes, for the same time period. This results in a gridlock in that particular part of town.

1.1.3.1.3 SCHOOL AND UNIVERSITY TRAFFIC

The February / March inbound arterial-delay was compared to that of June / July (school holiday) for 2013. During school and university holidays, when Stellenbosch is so-called 'dead', inbound morning (7am to 8am) arterial travel times are on average 54% that of term-time travel times. For the R310, and R44 from Somerset West, the inbound peak hour shifted from the morning to the afternoon. Noteworthy variances in town were noted along the R44 from the R44 / Van Reede Rd intersection to the R44 / Bird St intersection and along Bird St, Mill St and Piet Retief St to the R44 / Van Reede Rd intersection with reduced delays of 7 and 5 minutes, respectively. School and university traffic, thus greatly contributes to the overall traffic-congestion problem in Stellenbosch.

1.1.3.1.4 CUSTOM AREA ANALYSIS

A custom area analysis for the months February to March 2015 (Tuesdays to Thursdays) was also run using the TomTom Stats Portal. The graphical results help portray a non-scientific picture of the overall level of congestion in Stellenbosch, and help pinpoint the problem areas. ***Figure 1.3*** shows the

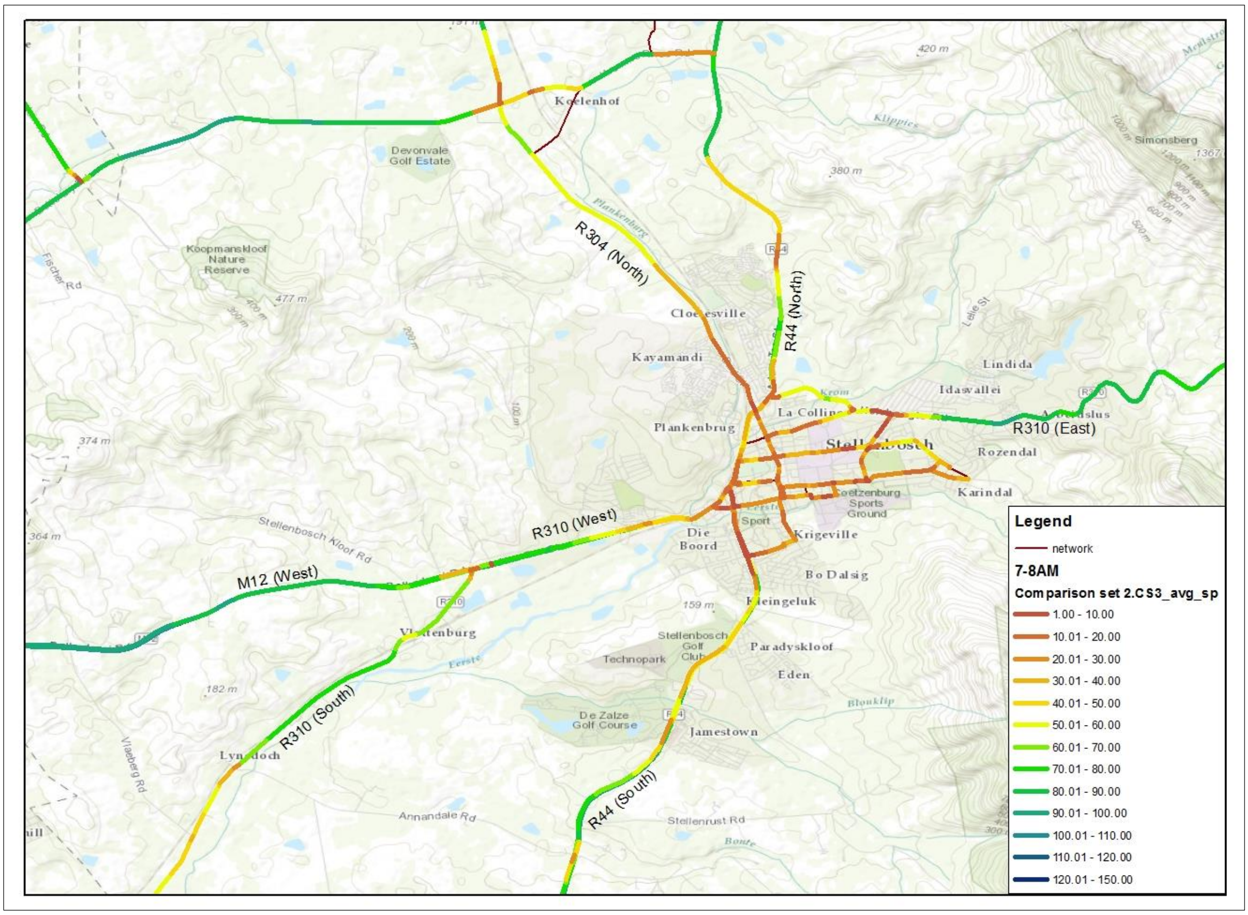


Figure 1.3: Depiction of the average travel speeds in Stellenbosch during the morning peak hour (7am to 8am) in 2015.

average speeds of the popular roads in Stellenbosch during the AM peak hour (7am to 8am). All the red and orange routes indicate very low travel speeds, and hence severe congestion.

1.1.3.2 ELECTRONIC QUESTIONNAIRES

Another study initiated by the author included the distribution of an electronic questionnaire to all the parents of seven schools in Stellenbosch (three primary and four high schools) to collect data on the travel characteristics of the learners, and assess the actual contribution of school trips to the overall morning travel-delay and congestion in Stellenbosch discussed in ***Section 1.1.3.1***. The schools encompassed in the survey were Bloemhof Girls' High, Eikestad Primary, Paul Roos Gymnasium, Rhenish Girls' High, Rhenish Primary, Stellenbosch Primary and Stellenbosch High. The schools were selected based on the fact that they are respectable schools that attract learners from beyond the Stellenbosch boundaries and from middle-class households for which, in most cases, the private light motor vehicle is the main mode of transportation. A similar questionnaire was distributed to the SU students and staff residing in the southern suburbs of / to Stellenbosch (the study area of this research project, *see* ***Section 1.3.3)***. The surveys also entailed questions that asked participants to rate the current traffic conditions either *en route* to school and in direct proximity of their school/s, or within a 2 km radius of the SU campus. The studies received ethical clearance from the Research Ethics Committee (REC) at Stellenbosch University, as well as institutional permission from the university's Division of Institutional Research and Planning (see ***Appendices B.2*** and ***B.3***). The study focused on the morning traffic, because the results of the probe data analysis revealed that arterial congestion is at its worst at this time of the day. The response rate from Stellenbosch High was very poor (only 22 respondents); the school was thus removed from the sample. For the other schools, a total of 951 households responded to the survey, which summed to a total of 1,184 learner responses. This relates to 20.8% of the total learner population. The university response rates were 10.3% (123 out of 1127) for students and 30.8% (131 out of 426) for staff.

The mean answer to the following five questions / requests:

parents

1. *"Regardless of travel mode choice, how does the traffic congestion on adjacent roads to the schools compare to that of the rest of Stellenbosch or the travelled route?"*
2. *"Please rate your frustration towards these traffic conditions."*
3. *"Please rate the morning traffic congestion within a 1 km radius of the school."*

SU students and staff

4. *"Regardless of your travel mode choice, please rate the morning (07:00 to 08:00) traffic congestion within a 2 km radius of the Stellenbosch University campus."*
5. *"Please rate your frustration towards these traffic conditions."*

were:

1. between "a lot worse" and "a little worse"
2. 7.1
3. 7.5
4. 8.4
5. 7.3

(where 10 represents the worst condition)

The surveys are discussed further in ***Section 4.7.1***, and more survey results are given in ***Chapter 7***.

1.1.3.3 TRAFFIC VOLUME COUNT AT R44 / VAN REEDE RD INTERSECTION

On 4 and 10 April 2013 (a Thursday and Wednesday, respectively) volume counts were completed by the Stellenbosch Municipality at the intersection of the R44 and Van Reede Rd to compare the traffic flow of a school day (10 April) to a non-school day (4 April, school and university holiday). The full results are shown in ***Appendix B.4, Table B-2***. In all cases, more traffic was present on the school day than on the non-school day. Important to consider for this research project were turn movements 2, 6, 7, 8, 9 and 10 (defined in ***Figure 1.4)***, as they lead to and from the schools. Turn movements 5 and 11 were also studied, however. The differences in vehicle numbers for these movements for

1. the full 12-hour day, and
2. the 7am to 8am time period

are shown in ***Table 1.1*** and ***Table 1.2***.

From these results no deduction can be made as to which extent the closed university and the closed school each had positive effects on the traffic on the non-school day. It is, nevertheless, clear that whilst peak traffic in Van Reede Rd does only comprise of school and university traffic alone, the traffic congestion is relieved when these educational institutions are closed for the holiday. Additionally, since it was the April holiday, it can be assumed that the general commuters were still at work.

1.1.3.4 EMME/3 TRANSPORT MODEL

In 2008, Jeffares and Green were appointed by the Stellenbosch Municipality to develop a strategic transport model for Stellenbosch. Cape Town's existing EMME/3 Metropolitan Transport Model was used as the basic transport modelling platform for the Stellenbosch one. 2001 census information and 2004 metropolitan-wide household-interview survey data were incorporated into the modelling

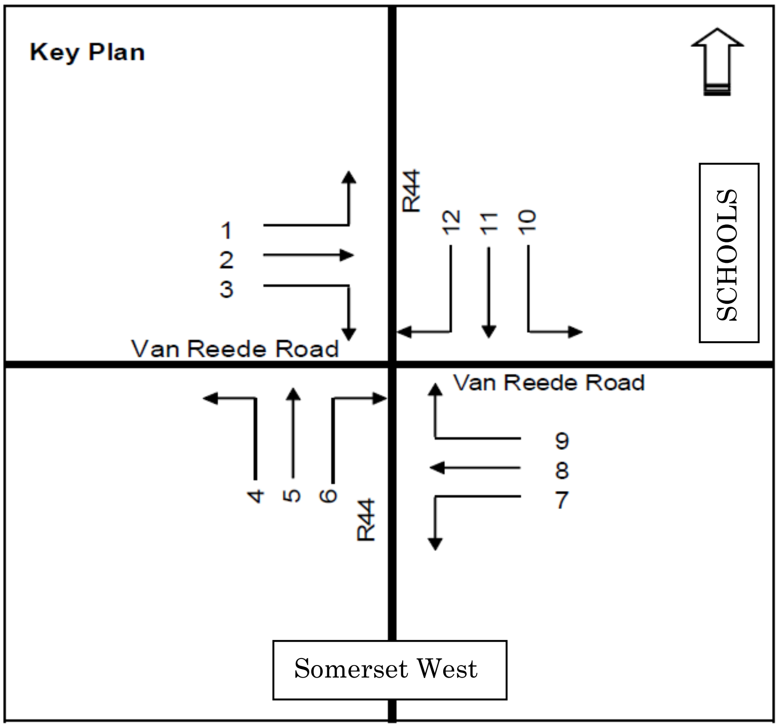


Figure 1.4: Numbering system used for the traffic count at R44 / Van Reede Rd intersection.

Table 1.1: 2013 R44 / Van Reede Rd intersection12-hour traffic volumes for a typical day versus a non-school.

Turn movement	Typical day (veh)	School holiday (veh)	Difference (veh)	Difference as a proportion of typical day volume
2	792	505	287	0.36
5	14,390	11,839	2,551	0.18
6	4,976	3,575	1,401	0.28
7	4,857	3,648	1,209	0.25
8	709	527	182	0.26
9	861	750	111	0.13
10	1,011	741	270	0.27
11	12,320	8,884	3,436	0.28

Table 1.2: 2013 R44 / Van Reede Rd intersection 7am to 8am traffic volumes for a typical day versus a non-school day.

Turn movement	Typical day (veh)	School holiday (veh)	Difference (veh)	Difference as a proportion of typical day volume
2	122	73	49	0.40
5	1,680	1,180	500	0.30
6	674	382	292	0.43
7	636	364	272	0.43
8	64	23	41	0.64
9	71	50	21	0.30
10	140	41	99	0.71
11	1,154	875	279	0.24

system. The base year in the model was set as 2011. The 2011 modelling results suggested that the following road sections would operate beyond their capacity:

- The R304 before it intersects with the R44*.
- The R44 south between Paradyskloof and the Van Reede intersection*.
- Bird St between the R44 and Du Toit St.
- Merriman Avenue (Ave) and Cluver Rd between Bird St and Helshoogte Rd.
- Dorp St between R44 and Piet Retief St*.
- Adam Tas Rd between its junction with the R44 and Merriman Ave*.
- Piet Retief St*.
- Van Reede and Vrede Rd between the R44 and Piet Retief St*.

For those routes included in the probe data analysis (marked with an asterisk), these results were proven accurate.

1.2 PROBLEM STATEMENT: THE NEED FOR NMT

The status quo discussed in ***Section 1.1.3*** verifies that there are simply too many vehicles on the extended Stellenbosch road network at specific hours of the day (i.e. the demand surpasses its capacity), and that long-term growth cannot be withstood. The greater part of intersections on the main roads operate at a Level of Service (LOS) F (Sinclair *et al.*, 2012), and in most instances, all probable alternative routes to a driver do not bestow any significant gain in terms of travel time and / or delay. The Stellenbosch Municipality is one of the fastest growing municipalities in the country, and peak-period traffic congestion will spread over a longer time span if capacity problems remain unresolved. In terms of the school learners surveyed, for an average 65.1% of high school learners, the mode of transportation to and from school daily is the private motor vehicle. For primary school learners, the average is as high as 85 to 90%. A prominent, but not exclusive, reason is that parents have the freedom of choice as to which school their child/ren attend/s - resulting in longer travelling distances to school when compared to previous generations (Carver *et al.*, 2013). Above and beyond the adverse travel and environmental impacts of traffic congestion, the economic consequences are momentous. Kumar *et al.* (2012) clarify why this is so:

> *"traffic congestion and its associated costs may decrease a city's productivity and limit its growth and development through a multitude of urban dynamics, including: (i) deterring companies from further investment in the city, worse still, driving companies to move away, (ii) consuming too much of the residents' time, energy and resources to permanently restrict their ability to improve their lives through skill upgrades or entrepreneurial activities."*

Sinclair *et al.* furthermore see the traffic congestion as an issue of road safety:

> *"congestion has also been shown to be a factor in the growing incidence of transport-related stress, potentially resulting in depression, aggression and disaffection, which have the potential to impact on driving behaviour and hence undermine road safety."*

1.2.1 ALTERNATIVE CONGESTION RELIEF MEASURES

It is apparent that the town of Stellenbosch urgently needs to move towards sustainable transportation and hence find a solution to the traffic congestion problem. Various congestion reduction strategies are presented in this subsection and reviewed in terms of their appropriateness to Stellenbosch. These strategies comprise roadway capacity expansion, transport pricing reforms, smart growth, transportation demand management, and improvements to the alternative / space-efficient modes. The final words lie with the need for NMT, however.

1.2.1.1 ROADWAY CAPACITY EXPANSION

Roadway capacity expansion is a congestion reduction strategy that is motor-vehicle orientated, and *"… can include new and expanded roads and bridges, wider and straighter lanes, intersection flyovers, traffic signal synchronizations, reduced cross-streets and crosswalks on arterials, reversible lanes, conversion from two-way to one-way streets, automated highway technologies, half-width vehicles, improved incident response, and various Transportation Systems Management (TSM) strategies"* (Litman, 2015). When any of these forms of expansion are implemented, authorities are indirectly stating that travel by private motorised transportation modes is accepted and supported. Although commonly considered, this strategy is costly and only a short-term solution, as urban sprawl will continue and more traffic will be generated (i.e. the congestion dilemma will present itself again over time). It is thinkable to balance the cost of roadway expansion projects through the use of road tolls. Tolls, however, often cause traffic volumes to decline on the tolled road, which not only causes toll road projects to fail in achieving their revenue targets, but also results in recurrent rat-running and congestion on adjacent roads.

In the case of Stellenbosch, the expansion of the existing road network is constrained by the town's historical buildings, its prominent aesthetic value and simply insufficient vacant land in the central business district (CBD). The capacity problem is evident when considering that the university has a shortfall of 3,500 parking spaces for the university population (Vela VKE Engineers, 2011), which is most probably even greater today. Allowing more traffic to enter the town only increases the demand for parking spaces even more. It thus becomes clear that the town cannot 'build' its way out of congestion.

Another option to reduce the congestion in Stellenbosch (already considered by the municipality) is the construction of bypasses that divert all through-passers in order to reduce their contribution to CBD-congestion. The author believes that this envisioned improvement will have marginal effects on the internal congestion though, as many trip destinations are located in town.

1.2.1.2 TRANSPORT PRICING REFORMS

Different transport pricing reforms can be implemented to reduce congestion. One such reform is congestion pricing, which refers to road tolls that charge road users higher fees during the peak hours to reduce traffic volumes and increase vehicle operating efficiency at these times of the day. Congestion pricing tends to have lofty implementation costs and raises concerns about privacy. Other pricing strategies include higher parking rates at times and places with a high parking demand, increased fuel taxes and distance-based pricing (i.e. pro rata vehicle insurance premiums and registration fees by vehicle miles travelled (VMT)). These tend to apply to a larger portion of road users, and hence tend to be more effective.

Transport pricing reforms are only fair though if alternative routes or modes are made available, since not all road users have a choice as to when and how much they travel. With no alternatives, road users are forced to pay, which (besides the complaints) does create revenue, but does not reduce congestion. There are the options to either price only one lane on a highway, so that motorists have an uncongested alternative, or have a designated High Occupancy Vehicle (HOV) lane that lower-occupancy vehicles may only use if they pay a toll. Stellenbosch neither has competitive alternatives available to its commuters, nor are any of the inbound / outbound roads highways. Pricing strategies will therefore, at least for now, not be able to provide the congestion relief the town is desperately seeking. It will only be efficient if implemented together with an alternative.

1.2.1.3 SMART GROWTH

According to Litman (2015), smart growth is *"… a general term for various policies that create more compact, multi-modal communities where residents tend to own fewer vehicles, drive less and rely more on space-efficient modes"*. There seems to be disagreement as to how much smart growth affects congestion. Among the main smart growth features are increased development density and a more connected road network. The former reduces trip distances, and the latter reduces the amount of traffic concentrated on the arterials. (Litman)

The town centre of Stellenbosch is already built up, and it would be near to impossible to redevelop it based on today's knowledge of the traffic congestion hotspots. For all the new developments to be constructed on the outskirts of Stellenbosch, smart growth features could form part of the planning process, but Stellenbosch's high commuter traffic and attractive destinations make the positive impacts this will have on congestion relief highly questionable; not every development can have its own educational institutions and CBD, for example.

1.2.1.4 TRANSPORTATION DEMAND MANAGEMENT

Transportation Demand Management (TDM) is a general term used for various strategies that increase transportation system efficiency, and as a measure of congestion relief encompasses an improvement in the availability of predictive and real-time travel information. This information (conveyed, for example, via Variable Message Signs (VMS), maps, radio, websites and mobile applications) allows commuters to respond to delays and alter their schedule, route or mode choice if necessary. As with the transport pricing reforms, the information is only a congestion reduction strategy when alternatives are available, which is currently not the case for Stellenbosch.

1.2.1.5 IMPROVING ALTERNATIVE / SPACE-EFFICIENT MODES

With the congestion reduction strategies discussed heretofore all ruled out as a solution to Stellenbosch's congestion problem, solutions are thus limited to optimising the efficiency of the current system (e.g. optimising traffic signal timings), but more importantly the search for alternative-mode transport systems, as optimisation is only sufficient up to a certain demand. Investing in transportation modes that require less space, such as NMT and public transit, is therefore a crucial solution to the urban logjam (Buis *et al*., 2000). ***Figure 1.5*** shows the amount of space occupied by 60 persons in light motor vehicles, a bus, and on bicycles. It is clear that cyclists and persons utilising public transit services occupy a lot less space on the roads. It is only on narrow, congested roads with moderate to high speed traffic, where faster vehicles cannot easily pass cyclists, that cycling can actually increase delay (Litman, 2015).

Comprehensive public transit in Stellenbosch is a plausible solution, but will only be efficient if the public transit vehicles travel with high occupancies; empty buses will increase congestion. It is thus NMT that stands out above all measures of congestion relief.

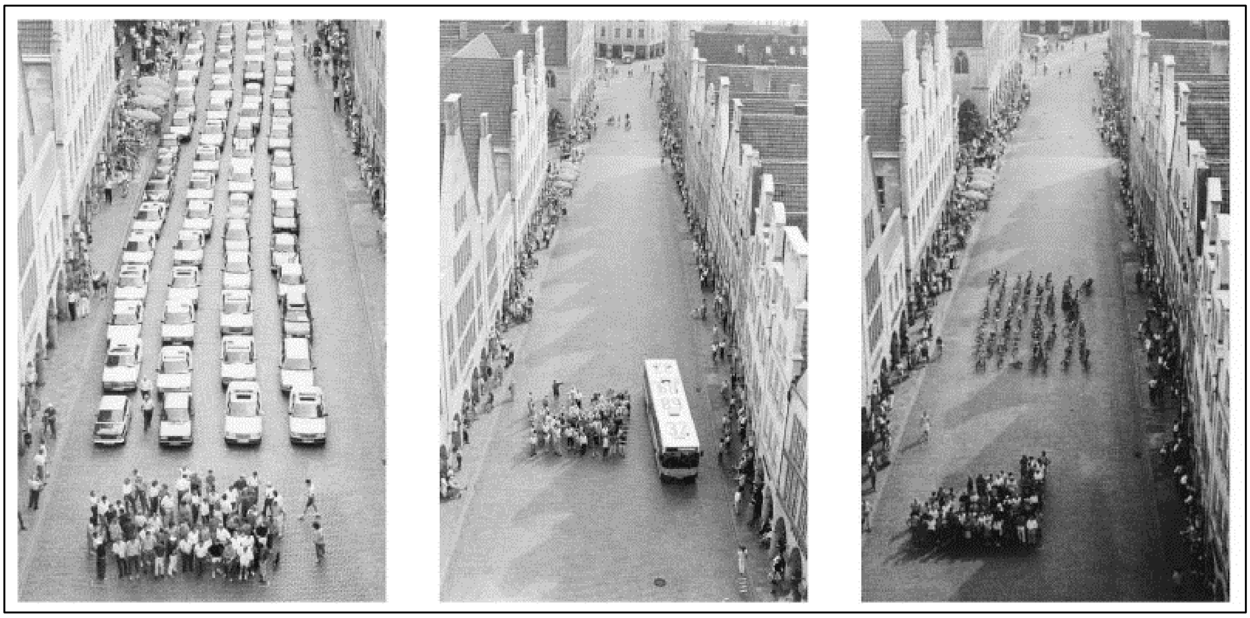


Figure 1.5: Space occupied by 60 persons and their respective modes of transport. (Kovach, 2013)

To quote the Stellenbosch Municipality (Stewart Scott International, 2010):

> *"Non-motorised Transport (NMT) as an essential daily transportation mode needs to be supported, developed and promoted in all environments to provide safe, direct, convenient and sustainable access to all destinations. Within the current social and economic environment, there is an urgent need to reduce our dependence on the (use) of private vehicles as a main transport mode to one that is conducive to walking, cycling and other forms of NMT."*

1.2.2 EXISTING NMT INFRASTRUCTURE AND PLANS FOR THE FUTURE

In South Africa, transport policy now strongly advocates for the development and prioritisation of cycling as a mode of transport. In December 2014, the Department of Transport released its *NMT Facility Guideline* – a revision and update of the existing *Pedestrian and Bicycle Facility Guidelines* (2003). The guideline aims to assist practitioners in the planning, design, implementation as well as maintenance of cycling, walking and other NMT facilities. Whilst no significant transformation of the Stellenbosch road network specific to cycling has taken place, there has been a substantial improvement in the general NMT network (mainly through the construction of NMT pathways). Given that some of these pathways are effective basic links for cycling, an initial network of safe cycle routes is emerging. These NMT improvements stem mainly from the proposed list of implementations in the two NMT plans that were prepared for Stellenbosch. These are:

1. *Stellenbosch Non-Motorised Transport Network Plan*, prepared in 2010 by Stewart Scott International (SSI)

   The study area covers the town Stellenbosch, which includes Kayamandi, Cloetesville and Idas Valley in the north, as well as Paradyskloof and Jamestown in the south. The other areas in the Stellenbosch Municipality were not included.

2. *Cape Winelands District Municipality (CWDM) – NMT Transport Masterplan Framework*

CWDM appointed Nisa Mammon & Associates SSI to prepare a NMT Transport Masterplan for the entire district, including the Stellenbosch municipal area, but excluding the Stellenbosch CBD.

NMT is also addressed in the Stellenbosch University Mobility Study and Stellenbosch Municipal Comprehensive Integrated Transport Plan (CITP), both prepared by Vela VKE (2010 & 2011). These plans discuss the enhancement and extension of NMT facilities in Stellenbosch, including bicycle lanes. It is also recommended that a policy for bicycle lockup and storage facilities is to be developed. A bicycle-sharing scheme is never considered, however. Furthermore, the Spatial Development Framework states the importance of car-free living. *Shaping Stellenbosch* is a spatial planning initiative of the Stellenbosch Municipality and Stellenbosch University. Between April and August 2014, members of the public were given the opportunity to submit ideas on the spatial development of Stellenbosch. NMT was one of the seven goals promoted in this initiative. Whilst this research project was not amongst the submissions, it is soothing to know that the municipality is open to ideas from the public. Moreover, the Stellenbosch Ratepayers Association (SRA), the National Cycling Academy (NCA) and EcoMaties are amongst the other groups backing NMT and pleading for an improved provision of NMT facilities.

The most relevant plan for this research project, and also the most important in terms of backing bicycle-sharing, is the 2015 *Cycling Plan for the Town of Stellenbosch,* prepared by Transport Futures (2015). In this research project, this plan will be referred to as the Cycling Plan from here on. The aim of the Cycling Plan is to guide and aid the advancement of cycling as a transport mode of choice in Stellenbosch and challenge the existing default choice of private motorised travel. Its vision describes what cycling in Stellenbosch will look like in 15 years' time: by 2030, cycling within and around Stellenbosch has become a popular form of mobility that is safe, convenient and is accepted and promoted by all. The eventual goal is to become the "Premier Cycling Town" of South Africa. The key focus of the plan was the preparation of an initial cycling network and infrastructure plan that is to be implemented in a series of stages, progressively improving and expanding the network. The strategy to safely accommodate cycling in the short (1 to 3 years) to medium (4 to years) term is to make significant use of widened general NMT pathways that provide basic route connectivity. In the medium and longer (8 to 15 years) term the focus changes towards intersection interventions and specific provision for cycleways on calmer lower-speed roads. Each area and road network link in Stellenbosch was surveyed and addressed in terms of proposed individual short- and long-term interventions. The interventions are described in more detail in ***Section 9.4.6***.

1.3 ABOUT THE RESEARCH AND ITS OBJECTIVES

This section elaborates on the research title and conveys the research statement, as well as the research objectives. It also justifies why a bicycle-sharing scheme is suggested as the NMT congestion-relief solution for Stellenbosch, and why the particular corridor from Somerset West along the R44 was selected as the case study of this research project.

1.3.1 RESEARCH STATEMENT

A bicycle-sharing scheme for school and university destined commuter traffic forms an integral part in achieving sustainable mobility in Stellenbosch, and is economically viable as a measure of congestion relief.

1.3.2 WHY BICYCLE-SHARING?

The Stellenbosch Municipality underlines that the focus on the development of the NMT network in Stellenbosch is to reduce the use of private light motor vehicles for short distance trips (trips shorter than 3 and 5 km, for walking and cycling respectively) and increase NMT usage through the provision of proper NMT facilities. While this objective will, no doubt, reduce traffic congestion, it neglects the many road users with origins and destinations outside of the CBD, i.e. not within cycling and walking distance. The results of the electronic questionnaire distributed to the schools revealed that the main barrier preventing learners from making use of active transportation (walking / cycling) is that the travelling distance is too long. For the high school learners surveyed, 53.1% live on the outskirts of Stellenbosch and beyond. A bicycle-sharing scheme operating from Drop-and-Gos and Park-and-Rides can extend NMT to these distance-travellers, and the proposed new cycling network discussed in ***Section 1.2.2*** lays a good foundation for this. If the cycling leg of the trip was replaced by walking, Drop-and-Gos and Park-and-Rides would have to be located a lot closer to the final locations, and would ultimately not contribute to *en route* congestion relief. And, to understand why a bicycle-sharing scheme is suggested instead of a shuttle service from these Drop-and-Gos and Park-and-Rides, one needs to look beyond the mobility benefits. A bicycle-sharing scheme is more economical in the long-term (it doesn't require expensive fuel or costly maintenance and repairs, and has a much lower investment cost), greener (no air pollution), healthier (improves physical activity), does not contribute to traffic congestion and offers the user more flexibility. (For a full list of benefits see ***Section 2.4.1.6)***. Shuttle buses would have to operate by completing several back-and-forth trips from the Drop-and-Go zones and Park-and-Rides to the popular destinations (too many buses defeat the point of congestion-relief even though the occupancy rate is higher than for most light motor vehicles), but what happens if they are caught up in traffic congestion and run late? Public transit priority schemes could be implemented, but this moves all remaining traffic into a confined space and could potentially increase congestion. And who (in the case of scholars and commuters that need to be at work at 08:00) would offer to wake up earlier to take the first shuttle? Bicycle-sharing is also seen as a major step towards making Stellenbosch the "premier cycling town" in South Africa.

1.3.3 RESEARCH OUTLINE

This research is an economic evaluation that evaluates the viability of the theoretical implementation of a bicycle-sharing scheme for school and university destined commuters in Stellenbosch as a measure of congestion relief. It forms part of a much greater project that aims to use Stellenbosch (and especially its university campus) as the test-bed for smart mobility applications in the South African context. The research comprises mainly a cost-benefit analysis that weighs the costs of the scheme (initial start-up costs and the maintenance or running costs) against the benefits the scheme is able to present in terms of mobility, health, the environment and the economy (e.g. congestion relief, travel-time savings, health improvements, emission reductions, fuel savings, etc.). A cost is any loss of total utility associated with the investment needed to establish the scheme. A benefit is regarded as any gain in total utility emanating from the bicycle-sharing scheme. The benefits are divided into direct benefits to the user, and indirect benefits to society and the authorities. It must be noted that the objective was not so much to determine absolutely precise benefit / cost ratios, but more to get an understanding of the magnitude of the values and determine whether such a scheme is economically viable or not.

Whilst this research is not the first to propose a bicycle-sharing scheme for South Africa (see ***Section 2.4.1.3)***, it is the first to propose such a scheme targeted mainly at scholars and university students. A general overview of the schools' and university's significant contribution to the overall traffic congestion in Stellenbosch has already been elucidated (see ***Section 1.1.3)***. It is believed that the cause of failure of previous attempts at implementing bicycle-sharing schemes in South Africa is that perhaps not the most ideal approach was taken. A scheme open to the general public has the potential for a greater uptake and the capacity to considerably improve the modal share of bicycles, but at the same time, it comes with a much greater risk (e.g. it is extremely difficult to estimate the demand for such rental facilities). South Africa is not a utility cycling nation, and one should not be fooled into believing that it will become one any time soon. Currently, there are simply too many barriers preventing a nationwide uptake of utility cycling. A bicycle-sharing scheme will always battle to be successful when the city / town lacks sufficient cycling infrastructure. Public funds should not be invested in bicycle-sharing schemes at the expense of cycling infrastructure (Kumar *et al*., 2012). High bicycle modal share can only be accomplished and kept up with safe, extensive and continuously improving cycling infrastructure. It is implausible that bicycle-sharing schemes (on their own) will have a pronounced impact on cycling levels, because the cost of bicycle ownership and maintenance is not typically the key issue inhibiting the choice of cycling in urban peak-hour commute (Kumar *et al*.). Furthermore, due to the sprawling and low density nature of South African cities, travelling distances are long, and unlike the case in many European cities, cycling cannot be easily combined with public transit. In terms of NMT infrastructure, Stellenbosch is not the average South African town, however; it is making immense progress in providing such facilities all across the town. What also makes this research unlike the others, is that it starts small - small in the sense of addressing a large proportion of a small target group, and not a small proportion of a large target group.

The implementation of the scheme is to be carried out in phases, as the uptake will vary for different target groups and it is believed that success will be achieved best this way. At first, the bicycle-sharing scheme is only to be made available to scholars, after which the scheme will be expanded for use by university students and staff. The economic evaluation of this research project covered these three groups, but bicycle-sharing is eventually to be made available to general commuters too (i.e. the general public) who are given the time to adjust to the idea and get fond of it. The university staff will most probably fall more into the group of general commuters, so provision for this assumption was made in the calculations. Tourists are accommodated from phase 1 (see ***Section 9.5.1***). It was important to target an audience that can be more easily convinced of the cycling benefits, and that is more likely to undertake a modal shift – hence the phased implementation. When new ideas, behaviours or technologies are to be adopted, the Diffusion of Innovation Theory explains how, over time, the innovation gains momentum and diffuses (i.e. spreads) through a specific population or social system. The theory was developed by E.M. Rogers in 1962, and is one of the oldest social science theories (Boston University School of Public Health, 2012). According to Rogers, people have different motivations for adopting a new idea. ***Figure 1.6*** shows the five adopter categories:

1. innovators,
2. early adopters,
3. early majority,

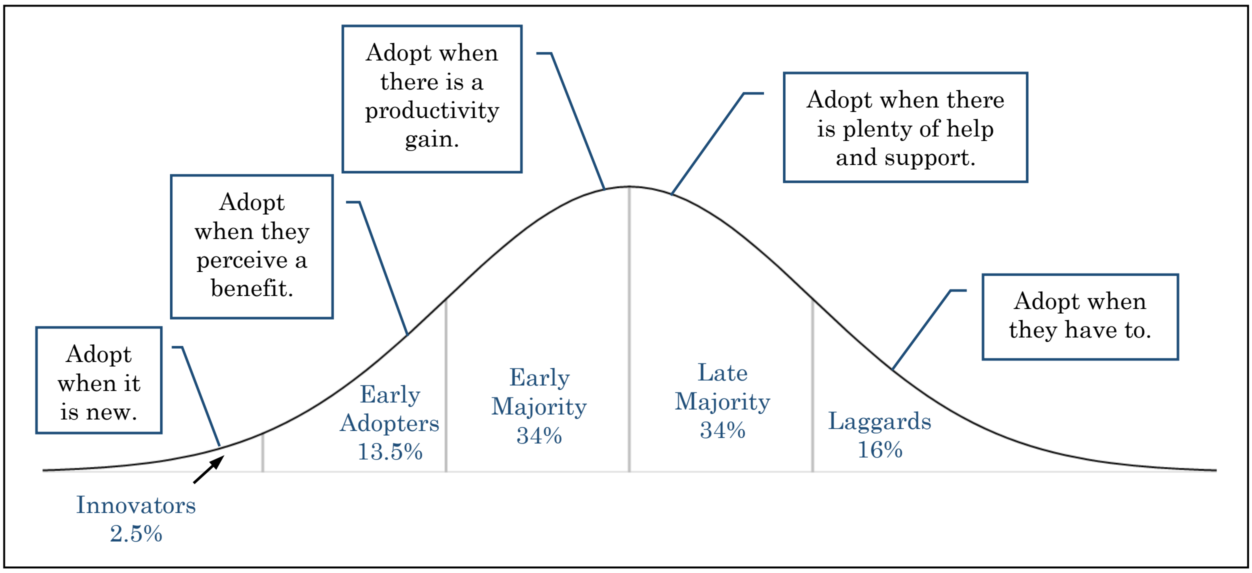


Figure 1.6: The five adopter categories of the Diffusion of Innovation Theory and the motivations for adoption. Adapted from D. Pearce (2013)

4. late majority,
5. and laggards

with their motivations for adoption. Whilst the innovators and early adopters only make up 16% of the total population, it is believed that in a closed environment of young individuals and parents, the early adoption numbers will be higher. This is partly because independent mobility is highly sought after by teenagers, and because parents are utterly frustrated with the current morning-congestion conditions. Furthermore, it is not only easier to address the non-anonymous learners and parents of a school environment than it is to address the general public, but the proposed bicycle-sharing scheme also scores high in the five main factors that influence the adoption of an innovation. These are:

1. *"relative advantage – the degree to which an innovation is seen as better than the idea, programme or product it replaces;*
2. *compatibility – how consistent the innovation is with the values, experiences, and needs of the potential adopters;*
3. *complexity – how difficult the innovation is to understand and / or use;*
4. *tria[la]bility – the extent to which the innovation can be tested or experimented with before a commitment to adopt is made; and*
5. *observability – the extent to which the innovation provides tangible results"*

(Boston University School of Public Health, 2012).

The traffic congestion along the R44 arterial from the Somerset West direction was selected as the case study for this research, because (as mentioned above) a bicycle-sharing scheme for scholars is to form phase 1 of the implementation and Krigeville (the suburb in which five schools are found in proximity of each other) is located at the entrance to the CBD from this direction. There were a total of 3,866 learners attending these five schools in 2014. This resulted in a vast number of regular private vehicle trips per day, mainly destined to, but also originating from, the same place at the same time. The school-drop-off trip times coincide with to-work trip times in the morning, which explains the major last-mile traffic congestion issues encountered at this time of day. The poor response rate from Stellenbosch High School has already been mentioned. This poor response rate is not the main motive for excluding Stellenbosch High School from the research, however. The results from Stellenbosch

Primary (sample size of 22.5%) clearly show that the morning traffic congestion is significantly better in Jonkershoek than in Krigeville (rating by parents of 5.7 out of 10).

The study area extends further into town than the defined corridor, because the impacts a decreased traffic flow on the corridor has on the traffic congestion in town is sought after. At the R44 / Van Reede Rd intersection, most of the vehicles either continue straight along the R44 or turn right into Van Reede Rd. The R44 eventually forms an intersection with Dorp St – the most congested street in Stellenbosch in 2014. At a point along its route, Dorp St also meets up with Piet Retief St – the road running parallel to the R44 along the back of Krigeville. As shown in ***Figure 1.7***, these roads shape a polygon around Krigeville, which in due course formed the study area of this research project's case study. The severity of the congestion in this area was shown in ***Figure 1.3***. ***Figure A.1*** in ***Appendix A.1*** is a map of the town of Stellenbosch on which the location of the more zoomed-in maps presented in the various chapters of this write-up are indicated. The location of Krigeville within Stellenbosch is indicated as Area 1 in ***Figure A.1***.

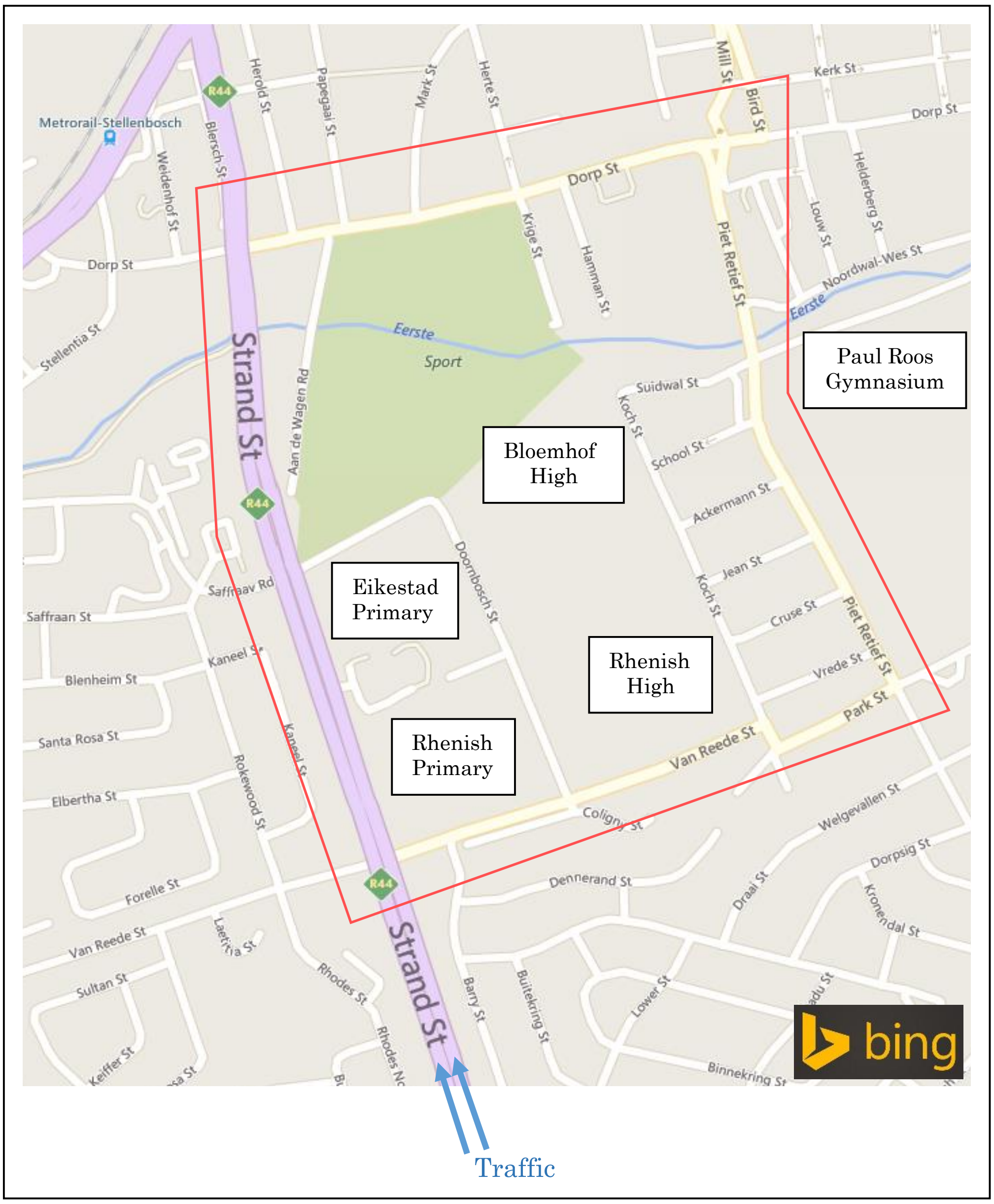


Figure 1.7: Map of Krigeville – the study area of this research project's case study.

In terms of scholars, the focus of this research lies specifically on high school learners, because primary school learners have a higher risk-exposure to accidents, and many learners are not yet competent to ride a bicycle to school by themselves (Kelly & Fu, 2014). This was confirmed by many surveyed primary school parents. With the special consent of their parents, primary school learners may, however, make use of the scheme, but they will be excluded from this initial research. In the case of the Jonkershoek area, a bicycle-sharing scheme thus also does not seem feasible for one school alone. The schools addressed in this research are thus Bloemhof Girls' High, Paul Roos Gymnasium and Rhenish Girls' High.

The bicycle-sharing scheme is to operate from Drop-and-Gos for scholars, and Park-and-Rides for university students and staff. These will be located within cycling distances to the schools and the university campus. Scholars are to be transported to these Drop-and-Gos in the mornings (mostly by private motor vehicles driven by their parents) from where their journey will be completed by bicycle. This system will operate in an opposite manner in the afternoon. SU students and staff, as well as general commuters will drive as far as the Park-and-Ride, park their motor vehicles there for the day and then also complete their journey by bicycle. People residing in direct vicinity of the zones may of course arrive at and leave the zone by foot. Docking stations will be positioned at these zones as well as at the schools and on campus. In the company of more NMT users on the commuter routes, Stellenbosch residents with short trips to school, university or work, may be encouraged and persuaded to undertake a mode shift to NMT too, either commuting by foot or by means of a bicycle (private or public).

1.3.4 RESEARCH OBJECTIVES

The primary objective of this research was:

1. to evaluate the economic viability of a theoretical bicycle-sharing scheme for school and university destined commuter traffic in the town of Stellenbosch as a measure of congestion relief.

The secondary objectives were:

i. to determine the first-order benefit and cost estimates of the proposed bicycle-sharing scheme for Stellenbosch (case study only) in the form of a Net Present Value (NPV), Benefit-Cost Ratio (BCR) and First Year Rate of Return (FYRR), so that the topic of bicycle-sharing can be considered as part of the town's political agenda should high values be attained.

ii. to conceptually design a premier bicycle-sharing scheme for Stellenbosch for school and university destined commuters so as to attain the highest possible NPV, BCR and FYRR.

1.3.5 SCOPE AND LIMITATIONS

The comprehensive design of the theoretical bicycle-sharing scheme lay beyond the scope of this research project. The design only went as far as necessitated to determine the relevant costs and benefits of such a scheme. A description of the operations is still included though, and enough details are given there, to understand how the system will be run. The research will also not provide a full description of the marketing or community outreach to be undertaken for the scheme before implementation. Suggestions and common practice found in literature will, however, be included. The same goes for funding sources. Business models applied internationally and their success stories will be discussed, and potential funding sources for Stellenbosch will be described and even recommended, but no details as to who funds how much will be provided. An important aspect with regards to scope is the cycling network and infrastructure. In this research project, it is assumed that cycling infrastructure, as described in ***Section 1.2.2***, will be put in place either before or in conjunction with the implementation of the bicycle-sharing scheme. Cycle-friendly interventions for each road network link in Stellenbosch were proposed by Transport Futures (see ***Section 1.2.2***), and these were assumed to be satisfactory for the theoretical bicycle-sharing scheme. There was thus no need to repeat this exercise, i.e. no detailed mention is made in this research project of the required *en route* infrastructure.

The potential benefits that were evaluated for the theoretical bicycle-sharing were very much dependent on the number of potential users determined. This calculation again was dependent on the results of the travel surveys. It needs to be said that it was assumed that the survey respondents were truthful when completing the survey.

The limitations of certain methodologies, and the assumptions that were made, are clearly described throughout the document. They are not included here, because they will not make sense before the respective methodology is introduced.

1.4 LAYOUT OF THE RESEARCH PROJECT

A summary of the chapters is given here. (A chapter comprises of sections and subsections.) All chapters form part of the build-up to the conclusion that affirms whether bicycle-sharing for school and university destined commuter traffic in Stellenbosch is economically viable or not. Each section in the document begins with an introduction, repeating what is said here in slightly more detail. The author believed it was necessary to split the standard 'Results' chapter into several individual chapters, because too many subsections would have arisen otherwise with even more heading levels than there already are.

Chapter 2: Literature Review

> This chapter introduces the concepts of sustainable transportation and smart cities, and makes the link to cycling, specifically bicycle-sharing. An overview of cycling in developing countries and in particular South Africa is provided to keep in mind the local context. The chapter then continues with a thorough review of bicycle-sharing literature and a look at travel behaviour change theories as well as marketing strategies and marketing activities. All the information in the chapter was essential for proposing and designing an appropriate and efficient bicycle-sharing scheme for Stellenbosch.

Chapter 3: Research Design

> Chapter 3 provides a framework of the overall approach that was taken to test the research statement of this research project. The approach was a combination of common research designs, each for which the application in the research project is discussed along with strengths and weaknesses.

Chapter 4: Methodology

> The methodology of the research project is defined in sequential order in Chapter 4, with reference made to the research designs discussed in the former section. The project alternatives

are described, the methods that were applied to calculate the costs and benefits of each of these alternatives are explained, and the employed economic evaluation techniques are made known.

Chapter 5 to 14: Results

In Chapters 5 to 14 the results of the methodologies defined in Chapter 4 for the different project alternatives are presented. Chapter 7 provides a summary of the travel survey responses, which was needed to determine the number of potential bicycle-share users in Chapter 8, and propose the particulars of the theoretical bicycle-sharing scheme for Stellenbosch in Chapter 9. The bicycle-sharing costs, revenue potential and benefits are presented in Chapters, 10, 11 and 12, respectively. In Chapter 13, the results of the cost / benefit analysis for the bicycle-sharing alternative are revealed.

Chapter 15: Conclusion and Recommendations

In Chapter 15, the problems come across in the research are shared, and a conclusion is drawn from the findings of the research on the appropriateness of bicycle-sharing for commuter traffic in Stellenbosch. Recommendations are also made for future research in the field of sustainable transportation, and specifically bicycle-sharing, for the town of Stellenbosch.

2 LITERATURE REVIEW

In this literature review, sustainable transportation and the smart city concept are introduced and explained, and the link to cycling, specifically bicycle-sharing, is made. An overview of cycling in developing countries, and in particular South Africa, is provided to get an understanding of the local context. The review continues with the history of bicycle-sharing and then thoroughly studies internationally existent bicycle-sharing schemes. In the final section, travel behaviour change theories, marketing strategies and marketing activities are explored for the successful promotion of such schemes. The information was essential for the conceptual design of an appropriate and efficient bicycle-sharing scheme for Stellenbosch. Reference to this literature is especially made in ***Chapter 9*** where the schematic plans for Stellenbosch are proposed.

To form the full link, though, between this literature study and the rest of the document, ***Table 2.1*** was drawn up. It maps the sections of this chapters with those where the literature was applied. A blank cell in the table does not mean that the information was of no importance, but rather that it served to provide more of a general understanding of bicycle-sharing schemes.

2.1 INTRODUCTION: SUSTAINABLE TRANSPORTATION

Our Common Future, also known as the Brundlandt Report, was released by the Brundlandt Commission of the United Nations in October 1987. It introduced and defined the meaning of the term **sustainable development**:

> *"… development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*

The document begins with the concern for a threatened future (the ability of Earth to support life as we know it is rapidly declining – social, environmental and economic systems are undermined), and describes the role of the international economy in sustainable development. The awareness scoped in this document has since provoked interest in a great number of sustainability strategies, such as **green engineering**, **smart cities** (see ***Section 2.2)*** and **sustainable transportation**. It is the concerns about global climate change, energy security and unstable fuel prices that have led many policy experts and decision-makers to closely assess the need for more sustainable transportation policies (Shaheen *et al*., 2010). The eventual accomplishment in sustainable development is said to be influenced by two main factors:

1. changes in human behaviour; and
2. the development of new sustainable technology.

Urbanisation has become a worldwide trend; the most rapid growth appearing in cities of less economically developed countries. This phenomenon, in addition to the increase in motorisation, has directly led to deteriorating traffic conditions, and indirectly to great economic and social expenditures, such as time lost in traffic, extra fuel consumption, air and noise pollution, and a lower quality of life (Kumar *et al*., 2012). With the fundamental role that transport plays in a nation's overall socio-economic development, the importance of designing, maintaining, and promoting sustainable urban mobility modes is becoming supreme (Lathia & Capra, 2012). Sustainable transportation development entails the integration of economic, social and environmental sustainability (Vanderschuren, 2006).

Table 2.1: Mapping of the literature review to the rest of the document.

2.1	Introduction: Sustainable Transportation		
2.2	Smart Cities: Introducing the Bigger Picture		
2.3	Cycling in Developing Countries	9.8	Equity Considerations
2.3.1	Cycling in South Africa	9.8	Equity Considerations
2.4	Bicycle-sharing Schemes		
2.4.1	Overview of bicycle-sharing schemes		
2.4.1.1	History		
2.4.1.2	Internationally existing bicycle-sharing schemes – where and how?	9.5	Description of proposed operation
2.4.1.3	Bicycle-sharing schemes in South Africa		
2.4.1.4	Business models – financing the scheme	4.6; 9.10; 10	Bicycle-sharing project costs; Business model; Bicycle-sharing cost analysis
2.4.1.5	Who is the typical cyclist?		
2.4.1.6	Benefits and disadvantages of cycling	4.7; 12	Bicycle-sharing project benefits; Bicycle-sharing benefits analysis
2.4.1.7	Barriers preventing cycling	3.3; 9.3; 9.4	Survey-based research; Siting considerations; Addressing the barriers
2.4.1.8	Sustainability – shifting from private motor vehicles to bicycles		
2.4.1.9	Average acceptable cycling distance	9.3	Siting considerations
2.4.1.10	Usage rates		
2.4.1.11	User tariffs	9.7	Membership and usage fees
2.4.1.12	Multimodal connectivity		
2.4.1.13	Trip purpose		
2.4.1.14	Rebalancing	9.5	Description of proposed operation
2.4.1.15	Maintenance	9.5	Description of proposed operation
2.4.2	The components of bicycle-sharing schemes		
2.4.2.1	Manual and automated systems	9.5	Description of proposed operation
2.4.2.2	Docking stations	9.2; 9.5; 9.6	System Parameters; Description of proposed operation; Specification of required equipment and infrastructure
2.4.2.3	The bicycles	9.6	Specification of required equipment and infrastructure
2.4.2.4	Cycling infrastructure	9.4	Addressing the barriers
2.4.2.5	Required resources	9.5	Description of proposed operation
2.5	Marketing Bicycle-sharing Schemes	9.9	Promotion of the scheme
2.5.1	Travel behaviour change theories		
2.5.2	Marketing strategies		
2.5.2.1	Undifferentiated marketing		
2.5.2.2	Differentiated marketing		
2.5.2.3	Concentrated marketing		
2.5.2.4	Individualised marketing		
2.5.3	Marketing activities		

Figure 2.1 illustrates the requirements of transportation services (with respect to each of these sustainable measures) necessitated for efficacious sustainable transport development.

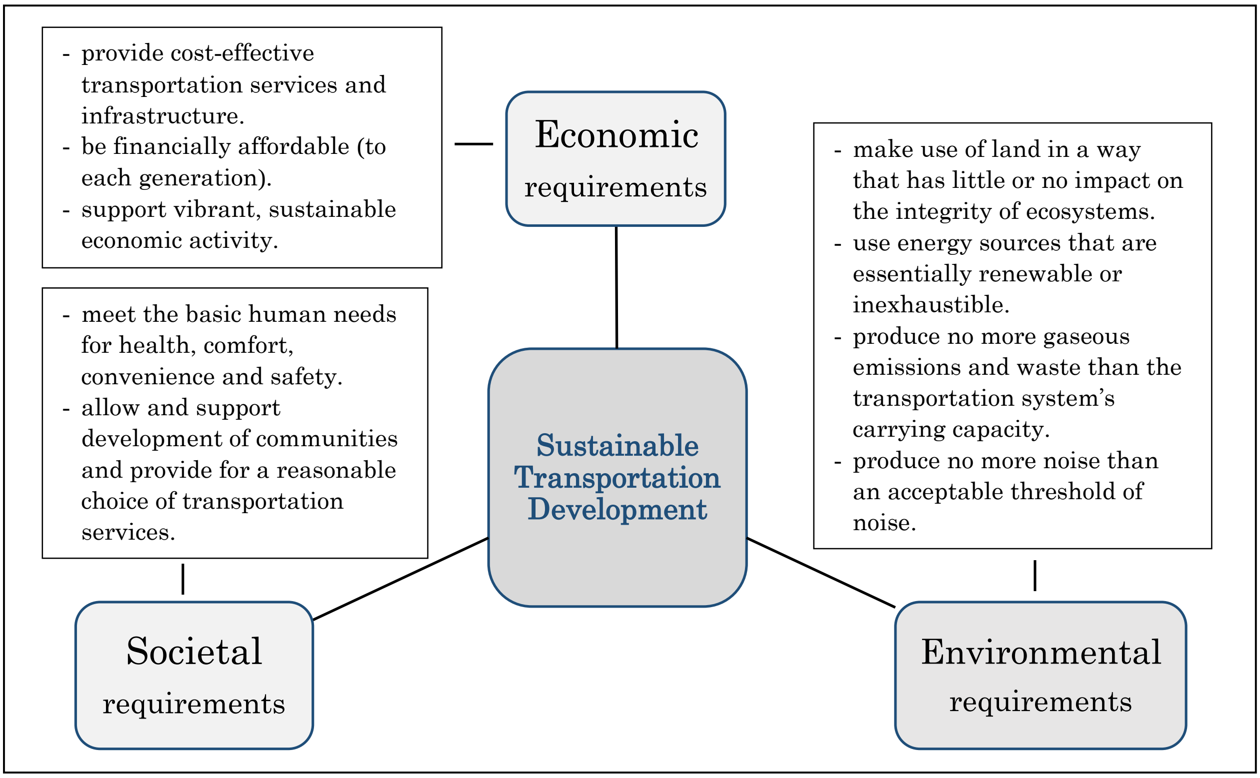


Figure 2.1: The requirements of transportation services for sustainable transportation development. Adapted from Vanderschuren (2006).

2.2 SMART CITIES: INTRODUCING THE BIGGER PICTURE

As said, the smart city concept is an approach towards sustainable development. In fact, the expectations are high on the potentials of smart mobility solutions to meet the increasing travel and transportation demands of the future, and address the issue of climate change. To accomplish this aspiration, smart city planning demands the joint efforts of industry, knowledge institutes and government. According to Boyd Cohen (2012), smart cities are

> *"a broad, integrated approach to improving the efficiency of city operations, the quality of life for its citizens, and growing the local economy".*

In his 'Smart Cities Wheel', he introduces the six aspirational goals of smart cities: having

1. a smart economy;
2. smart environmental practices;
3. smart governance;
4. smart people;
5. smart living; and
6. smart mobility.

A city is defined as smart when it displays a positive performance in all the six areas. Three key drivers to excelling in each area are included in the wheel: those for smart mobility are shown in ***Figure 2.2***, and are multi-modal access, clean and non-motorised mobility, as well as integrated Information and

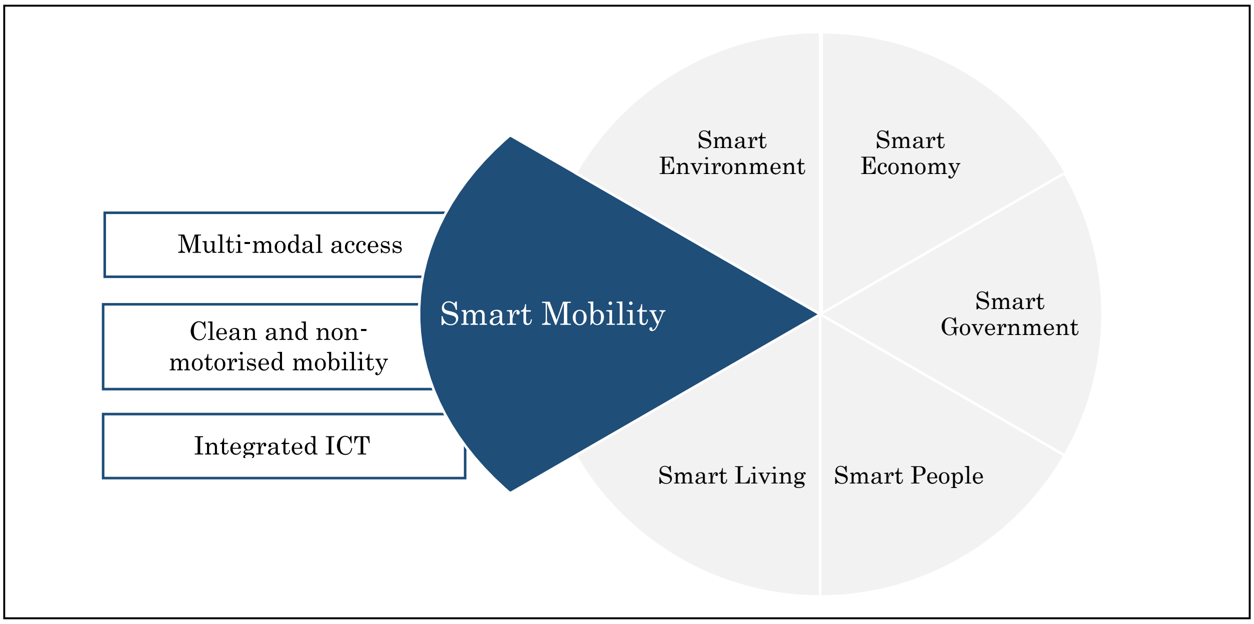


Figure 2.2: Part of the Smart Cities Wheel. Adapted from Boyd Cohen (Fast Company, 2012).

Communication Technology (ICT). The application of ICT leads to better use of the available infrastructure based on a change towards a central point of user control.

On the whole, it is the use of technology that plays a dominant role in enhancing the positive performance. For smart mobility, technology can be found in the form of autonomous vehicles, vehicle-to-vehicle communication, vehicle-to-infrastructure communication, crowd sourcing, advanced traffic light signal control systems, alternate power sources, in-vehicle Intelligent Transport System (ITS) telematics, Global Navigation Satellite System (GNSS) based location-aware applications, intelligent fleet management systems and integrated transportation management systems. In all cases, large sets of data are collected (referred to as big data), which need to be processed to uncover patterns and useful information. The process is known as big data analytics – one of the hot topics of the decade in the field of technology. In essence, the technology will allow transport users to base their mobility choices on the performance of the mobility system due to smarter connectivity and easy access to a wide variety of real-time information (e.g. forecast and real-time event information services, traffic conditions information, speed limit information, travel time information, incident warning management and incident management) before and even during their journeys. People can also share resources and pay for multiple stages of a journey at once without cash through smart payments. The required levels of deployment of ITS services and technologies will typically vary with the service levels: higher service levels often require other or more sophisticated technologies.

A study performed by Netherlands Organisation for Applied Scientific Research (AutomotiveNL *et al.*, 2012) showed that

> *"smart mobility initiatives will lead to 50% fewer traffic jams in the next 10-15 years, 25% fewer traffic fatalities, 10% lower CO_2 emissions and 20% lower air pollution".*

2.3 CYCLING IN DEVELOPING COUNTRIES

In many developing countries, cycling typically has a negative status among the entire population, and is associated with poverty. On that account, the bicycle is more often than not a captive mode (no alternatives available), rather than a choice mode, and as a result receives little funding and investments. The future impacts of a lack of NMT facilities are often overlooked. The urban poor group forms (and will most likely remain) the most conventional and faithful user group of NMT modes, and it should thus be ensured that they are not forced to shift to private motor vehicles due to a lack of such facilities (i.e. motor vehicle dependence should be prevented at all costs). (Dhingra & Kodukula, 2010)

2.3.1 CYCLING IN SOUTH AFRICA

The results of the latest (2013) National Household Travel Survey (NHTS) conducted in South Africa, showed that the modal share for cycling is a dismal 1.3%. Utility and urban cycling is close to absent in South African cities. This is distressing, because low income commuters in Southern Africa would save on average 20% to 45% of their monthly household income if their mode of transportation was the bicycle instead of public transit (Bechstein, 2010). The sport / leisure combination adds up to more than half the bicycle use; this is primarily due to Pedal Power Association (PPA) - the largest recreational cycling organisation in South Africa (De Waal, 2000). Founded in 1976, PPA came into being as a result of running the first Cycle Tour that over time developed into the now-world famous, annual Cape Argus Pick 'n Pay Cycle Tour.

The NHTS is only carried out every 10 years, which makes assessing the immediate impacts of strategies and projects challenging. It is also a general survey that is not specifically focused on bicycles. Nonetheless, an independent study found a 30% increase in scholar bicycle commuting after the completion of Cape Town's 22 km network of bicycle paths in the Rondebosch / Newlands area. (De Waal, 2000)

In the past, multimodal connectivity between public transit and cycling was difficult, because bicycles were not permitted on most public transit. Whilst this is still so for the popular minibus taxis, bicycles are welcome on Cape Town's Integrated Rapid Transit System (IRT) - *MyCiti* - and Passenger Rail Agency of South Africa (PRASA) has also announced that they have no aversion to commuter cyclists bringing their bicycles onto the trains. The problem of an inadequate public transportation remains nevertheless.

Under South African law, bicycles are regarded as vehicles (National Road Traffic Act, no. 93 of 1996). This means that cyclists have as much right to be on the roads as light motor vehicles, taxis or buses. As a result, traffic laws also need to be obeyed by cyclists. While motorists need to keep a 1 m passing distance, cyclists are required to cycle in single file at all times, unless overtaking or during official races. South Africa has few dedicated bicycle lanes; this implies that cyclists are fighting for road space every day. For safety reasons, it is thus of utter importance for both parties to adhere to the traffic laws.

2.4 BICYCLE-SHARING SCHEMES

2.4.1 OVERVIEW OF BICYCLE-SHARING SCHEMES

In the developed world, bicycle-sharing schemes have been recognised by many governments and transportation professionals as a powerful catalyst for the shift towards smart cities, and particularly sustainable transportation. Bicycle-sharing schemes are often referred to as 'the revival of the bicycle', and have the ability to form a critical part in accomplishing smart mobility. Naturally, the technological advancement of the individual scheme determines to which extent this is possible, and how many key drivers can be addressed; but the first two ('multi-modal access' and 'clean and non-motorised mobility') are virtually guaranteed.

In terms of sustainable transportation specifically, bicycle-sharing schemes fulfil their obligation towards the environmental protocols, a target that is becoming more and more challenging for other modes to reach, because of their gaseous emissions (Efthymiou *et al*., 2013). Bicycle-sharing schemes are furthermore, the cheapest means of reaching this target (Buis *et al*., 2000). It is important to mention though that the ultimate goal of an overall sustainable transportation system is not reached simply by having a bicycle-sharing scheme in place; bicycle-sharing is merely a step (a major one if successful), amongst many others, towards achieving this goal (Dhingra & Kodukula, 2010).

Bicycle-sharing schemes are also intended to fill the gap in the urban transportation network between walking and transit / private motor vehicle travel, where the distance to a certain destination is too far to walk, but at the same time too close to justify incurring the cost of a private motor vehicle trip (for which parking is also required) or waiting for transit (Daddio, 2012). Urbanisation, referred to in the introduction of this chapter, signifies a continuous expansion of cities and an increase in journey distances as a result (Buis *et al*., 2000). Whilst many central destinations may have been accessible by foot in the past, this is no longer the case, and an alternative mode of transportation (e.g. the bicycle) is called for. ***Figure 2.3*** exhibits the gap which bicycle-sharing schemes fill within the urban transportation network.

Numerous cities in Europe have validated that preserving the cycling culture and endorsing it as a key mode of transportation, conserves the heritage as well as the modern lifestyle of the city, and therefore also its future liveability (Dhingra & Kodukula, 2010). This is, however, only possible with enthusiasm, interest and backing on the part of the government. The PRESTO Cycling Policy Guide (2010) distinguishes cities according to their level of cyclic development as starter, climber and champion cities. Cycling development is dependent on two indicators: cycling conditions and the cycling modal split, both of which can be improved with the implementation of a first-rate bicycle-sharing scheme. The stages are shown in ***Figure 2.4***.

2.4.1.1 HISTORY

Bicycle-sharing schemes have evolved from being appealing try-outs in urban mobility, to mainstream public transportation in cities as large and multifaceted as London and Paris. The first scheme ('White Bike Plan') was launched in the 1960s in Amsterdam, the Netherlands. It was the first of four generations of bicycle-sharing schemes. The ordinary, white-coloured bicycles (provided for public use for free) were damaged and stolen, however, and the programme terminated within days. The second generation, first launched in Copenhagen (Denmark) in the mid-1990s, was based on specially manufactured coin-deposit bicycles: bicycles were unlocked with a 20 Danish kroner coin that was

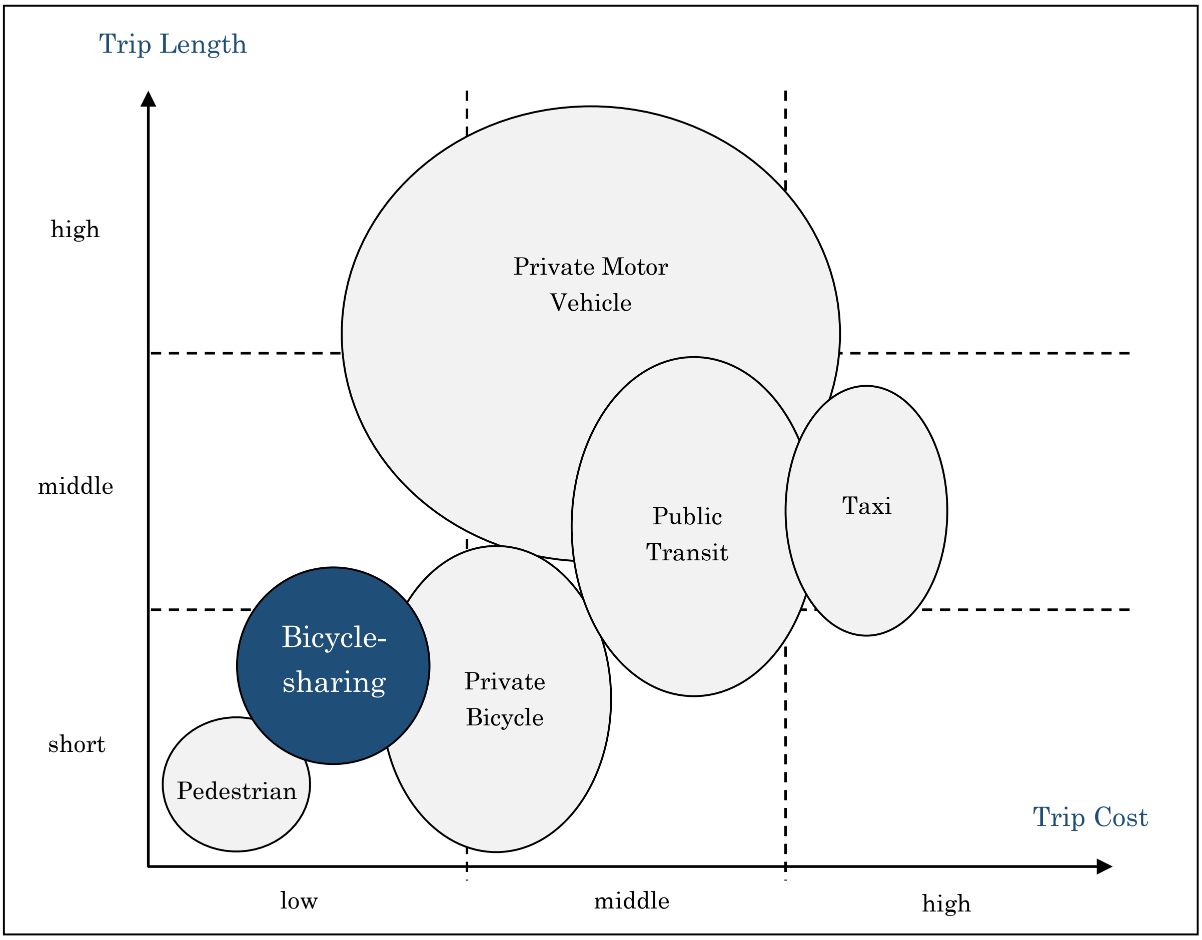


Figure 2.3: The gap bicycle-sharing schemes fill within the urban transportation network. Adapted from Quay Communications Inc. (2008).

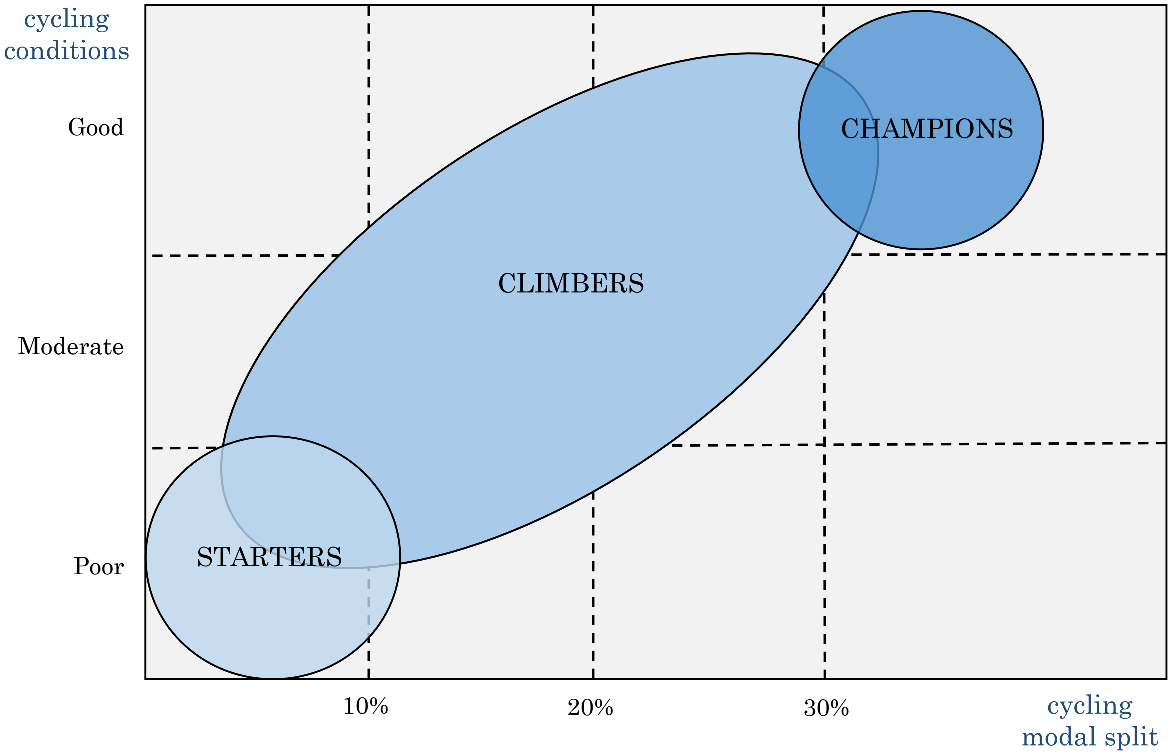


Figure 2.4: The levels of cyclic development in a city. Adapted from PRESTO (2010).

refunded upon bicycle return. The theft of bicycles attributed to customer anonymity continued to be a problem, which necessitated a third generation bicycle-sharing scheme. This generation makes use of IT: electronic bicycle locking racks or locks, user-interface check-in and check-out of bicycles, Global Positioning System (GPS), tracking devices, and real-time user information on station parking and bicycle availability. The use of electric bicycles, inducements to users to return bicycles to docking stations with high demands, moveable and solar-powered docking stations, improved interoperability with other modal systems, and mobile applications point towards a fourth generation (Efthymiou *et al.,* 2013; Midgley, 2011).

2.4.1.2 INTERNATIONALLY EXISTING BICYCLE-SHARING SCHEMES – WHERE AND HOW?

An online bicycle-sharing blog – *The Bike-sharing Blog* – provided by MetroBike, LLC, shares worldwide up-to- date happenings related to bicycle-sharing, and thus reflects on its development as a state-of-the-art mode of public transportation. The bloggers are P. DeMaio and R. Meddin. The *Bike-sharing World Map* complements the blog and clearly shows the global dispersion and new implementation of bicycle-sharing schemes. In addition, the map presents a short description on each existing scheme, forming it into a platform that offers easy access to the latest information on specific bicycle-sharing schemes and an opportunity for cities interested in bicycle-sharing to learn from existing programmes.

At the end of 2014, 853 cities worldwide had a bicycle-sharing scheme in place, with a total public bicycle fleet of 946,000 bicycles (Meddin, 2015). The prompt growth of bicycle-sharing cities is shown in ***Figure 2.5***. These cities span from North and South America along Europe, the Middle East and Asia, to Australia and New Zealand. The list includes a number of cities of developing countries, such as Brazil, Chile, China, Columbia, Cyprus, India, Islamic Republic of Iran, Mexico, Israel and Turkey. The largest and most renowned schemes are found in the Netherlands (*OV fiets*), Paris (*Vélib'*), London (*Santander Cycles*), Montreal (*BIXI*), Washington, D.C. (*Capital Bikeshare*) and Hangzhou. The countries with the highest fleet count are shown in ***Figure 2.6*** – with China being the clear frontrunner. Asia's and South America's adoption of bicycle-sharing did not begin until the third generation (Shaheen, *et al.*, 2010).

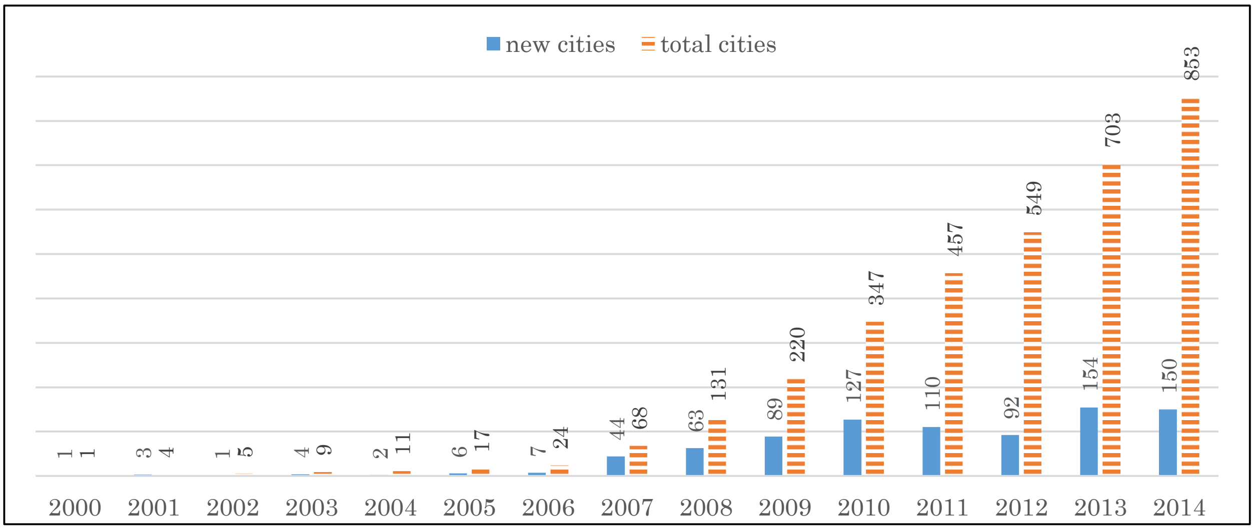


Figure 2.5: Worldwide bicycle-sharing city growth. Adapted from Meddin (2015).

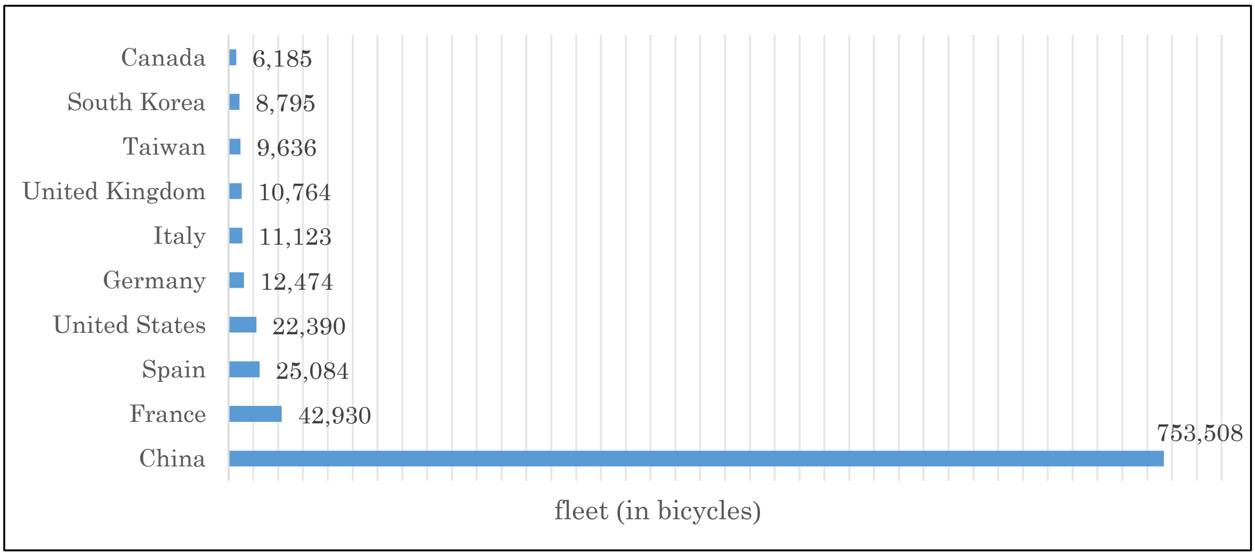


Figure 2.6: Countries with the highest bicycle-share fleet count. Adapted from Meddin (2015).

It is, in fact, the development of the third and fourth generation public bicycles that enabled the considerable growth in bicycle-sharing schemes worldwide.

Most cities have implemented *community* bicycle-sharing models, where the user checks out a bicycle from any self-service bicycle station and returns it to any other bicycle station within the system's service area. The stations are typically spaced 300 m apart from one another. The *residential* model (bicycle is returned to the station where it was checked out), which is applied in Japan, is designed for denser cities (DeMaio & Gifford, 2004). There are two readily employed locking technologies in bicycle-sharing schemes; the one applies to the bicycle racks and the other to the bicycles themselves. For the former, bicycles are checked out with the use of a smart card or magnetic stripe card. ***Figure 2.7*** depicts a system diagram of a typical third generation bicycle-sharing scheme that makes use of this first technology. The second locking technology requires the user to communicate via a mobile phone for an unlocking code. This technology is used by the public transportation agency Deutsche Bahn, Germany. Once the code has been entered on the touchscreen, the bicycle is unlocked. After a completed journey, the user presses the lock button on the touch screen to receive another code. The user then has to phone the hotline, enter the lock code and leave a voice message communicating the location of the bicycle (Dhingra & Kodukula, 2010). This location is sometimes required to be a major intersection.

2.4.1.3 BICYCLE-SHARING SCHEMES IN SOUTH AFRICA

The cities of Cape Town (CoCT), Durban, Johannesburg (CoJ) and Pretoria have all considered the idea of implementing a bicycle-sharing scheme. As part of the CoCT's Travel SMART Programme, a pilot staff bicycle-share project was launched in the CoCT in April 2013. Six bicycles (imported from the Netherlands) are available for official city business use to travel between *Civic Centre* and *44 Wale St*. In addition, the city is looking into the feasibility of setting up a bicycle-sharing network of bicycles and depots around the inner city that can be accessed with a smartcard, e.g. the 'myconnect' card used for the MyCiti buses. The scheme was expected to launch towards mid-2015 (Stear, 2013). Interestingly, a bicycle-sharing scheme had been considered before and was initially included in the business plan for the CoCT's IRT system, but was later withdrawn due to budget cuts (Jennings, 2011). The CoCT had also considered a pilot bicycle-rental system for the 2010 FIFA World Cup event and its associated visitor transport (Jennings). Six rental stations were proposed to be constructed around

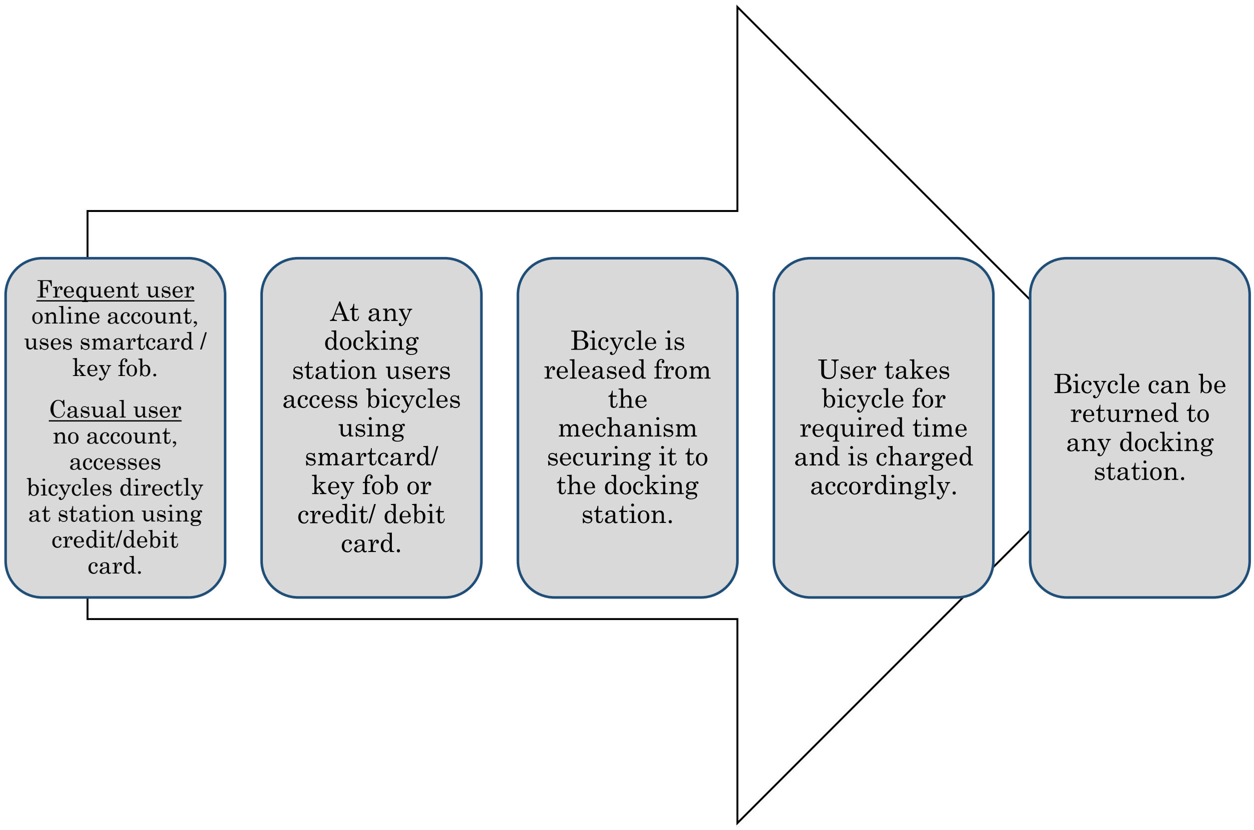


Figure 2.7: System diagram of a typical third generation bicycle scheme. Adapted from Parkes et al. (2010).

Green Point Urban Park, the *V&A Waterfront*, the *Convention Centre* and *Green Point stadium*. The scheme's objective was to market and promote cycling rather than address transportation failures during the event, and to evaluate the need for a continuing system. The system (aimed at tourists) was to have been labour intensive, i.e. staffed by mechanics who would oversee the system, as well as guard, clean and repair bicycles as necessary. The pilot project was never implemented, again due to a lack of financial resources, among other reasons. A similar scheme, namely 'Up Cycles', is now up and running, however. This all-year-round, privately-owned scheme, used mainly by tourists, has three docking stations, viz. *Clock Tower Square* (*V&A Waterfront*), *Sea Point Promenade*, and *Hotel Mandela Rhodes Place*, *Wale St*. Nine temporary lock-ups are furthermore located within the coverage area. The *Discovery Vitality Bikes* of the scheme are single speed, back pedal-breaking bicycles from the Netherlands. The fees of the scheme are as given in ***Table 2.4*** on page 39. Up to 2011, bicycle rental companies in the CoCT were barely covering costs or breaking even. During the peak tourist season in 2010 / 2011, for example, a bicycle rental at the *V&A Waterfront* was renting out one bicycle a day, only to tourists – not locals (Jennings). This is expected to improve with the enhancement of bicycle infrastructure.

Durban's city mayor, J. Nxumalo, presented the metropolitan's NMT initiative in June 2014, confidently stating,

> *"this is a city for people, not a city for cars".*

He said that the NMT would be accompanied by a bicycle-sharing scheme that is at first only for municipal staff as a pilot project, with the ultimate goal of being expanded to several areas in the city. The NMT is to be launched in conjunction with '*GO!Durban*', the city's IRT network, which will commence operation in 2016 and grow in phases thereafter over a period of 15 years (traveller24, 2014).

The City of Tshwane also hoped to introduce a labour-intensive bicycle rental scheme during the 2010 FIFA World Cup by partnering with the Department of Transport's Shova Kalula programme; this too was never implemented (Jennings, 2011).

In 2013, the CoJ commissioned GIBB to assess the technical and financial viability of piloting a bicycle-sharing scheme in one of five potential areas. Although bicycle-sharing was found to be technically feasible, none of the evaluated scenarios were estimated to cover their operational costs, and it was consequently concluded that financial investments should rather be made in initiatives that increase people's access to cycling (De Beer & Valjarevic, 2015). It is imperative to note that the case study for the CoJ greatly differs to the one described in this research project. It seems that the main objective of the scheme was not to mitigate traffic congestion, because if so, at least the mobility benefits of the scheme should have been evaluated and weighed against the costs of the scheme, so that financial investments are put into perspective. The focus also lay on the lower-to-middle income group opposed to the middle to high income groups.

Nevertheless, from the literature, it seems that South African cities are taking good steps towards acknowledging the potential of NMT, and especially that of bicycles. It should not be ignored, however, that South Africa is a developing country that still faces many challenges with respect to NMT, and it may not be possible, enough nor sensible to simply replicate a scheme from developed countries. In the developing-country context it is, for example, a poor assumption to assume that all people have a credit card. A deposit, such as an identity document or driving licence, does not allow for one-way point-to-point trips, however – one of the foremost pros to bicycle-sharing (Midgley, 2011). All this needs to be considered. Jennings (2011) also suggests that bicycle-sharing schemes

> *"risk attracting criticism from organisations such as [Congress of South African Trade Unions] COSATU, ever watchful of bicycle infrastructure that is merely a gimmick for the wealthy".*

2.4.1.4 BUSINESS MODELS – FINANCING THE SCHEME

2.4.1.4.1 CAPITAL AND MAINTENANCE COSTS

The costs of implementing a bicycle-sharing scheme are divided into two types: initial start-up/capital costs and maintenance / running / operating costs.

The capital costs include the construction of bicycle infrastructure (e.g. bicycle lanes), bicycle purchase, docking station equipment and construction, purchase or rental of maintenance and distribution vehicles, member access cards, licence or purchase of the back-end system used to operate the equipment, and installation. The handbook *Optimising Bike Sharing in European Countries* (IEE, 2011) gives an approximate breakdown of the infrastructure and implementation costs for *Bicing* in Barcelona (see ***Table 2.2)***. Station implementation accounts for 70% of the total infrastructure and implementation costs; bicycles only for 17%. In Paris, the initial system costs were around EUR[1] 90 million (approximately ZAR 1.33 billion) for the installation of 20,600 bicycles, which amounts to ZAR 56,971 per bicycle (Transport Canada, 2009). Midgley (2011) says that capital costs can range between

[1] The exchange rate from Euros (EUR) to South African Rand (ZAR) was taken as 1 to 14.75, as on 22 August 2015.

Table 2.2: Example of infrastructure and implementation costs for Bicing in Barcelona. Adapted from IEE (2011).

Infrastructure and Implementation	Share of total costs
Station implementation: terminals, docking points and locking technology, station planning, ground work and cabling	70%
Bicycles	17%
Set-up operations: workshop and logistics	6%
Communication	5%
Administration	2%

USD[2] 3,000 and 4,500 (ZAR 38,850 and 58,275) per bicycle. The financial assessment for a bicycle-sharing scheme for the Alexandra-Sandton route in Johannesburg (mentioned in ***Section 2.4.1.3)*** stated implementation and cost capital cost estimates ranging from R505,216 (40 bicycles, 2 stations, small no-tech entrepreneur driven system) to R32.64 million (1000 bicycles, 100 stations, large scale manual system). The per-bicycle capital-cost range for the Johannesburg scheme was thus estimated to be R12,630 to R32,640.

Running costs include office space, staff, electricity charges, insurance, redistribution of bicycles, storage facilities, website hosting and maintenance, membership cards and warehouse / storage fees. IEE (2011) also gives a breakdown of the running costs for *Bicing* in Barcelona (see ***Table 2.3.***).

Table 2.3: Example of running costs for Bicing in Barcelona. Adapted from IEE (2011).

Running Costs	Share of total costs
Redistribution of bicycles	30%
Bicycle Maintenance	22%
Station Maintenance	20%
Back-end system	14%
Administration	13%
Replacement (bicycles, stations)	1%

NICHES (2007) cites the yearly operating costs (per bicycle per year) for the schemes in Lyon and Rennes to be EUR 1,000 (ZAR 14,750). Transport Canada names a source that suggests that these costs should be much higher – anywhere from EUR 1,400 to 3,900 (ZAR 20,650 to 57,525) per bicycle per year. Midgley (2011) gives annual maintenance costs between USD 1,200 and 1,700 (ZAR 15,540 and 22,015). Unforeseen costs, such as the theft and vandalism of bicycles, are usually considered as part of the maintenance costs, and these costs tend to vary depending on the technology installed on the bicycles (Dhingra & Kodukula, 2010). In Europe, the replacement costs for public bicycles range from EUR 250 to 1200 (ZAR 3,688 to 17,700) (NICHES, 2007). For the Johannesburg bicycle-sharing scheme the range of annual running costs was estimated at R1.068 million (40 bicycles, 2 stations, small no-tech entrepreneur driven system) to R23.27 million (1000 bicycles, 100 stations, large scale

[2] The exchange rate from US dollars (USD) to South African Rand (ZAR) was taken as 1 to 12.95, as on 22 August 2015.

labour-intensive manual system). The per-bicycle running-cost range for the scheme of Johannesburg was thus estimated to be R23,270 to R26,700.

2.4.1.4.2 BUSINESS MODELS

With the widespread growth of bicycle-sharing, several business models with varying operators have developed for deploying, operating and funding these schemes. It has become common practice for bicycle-sharing to be operated as public-private partnerships with large advertising companies. In exchange for advertising space in the public domain, the advertising company obliges to provide and operate the scheme. Three of the largest international advertising companies committed to bicycle-sharing are *Cemusa, JCDecaux* and *Clear Channel* – they account for 20% of all schemes (Midgley, 2011). To the municipality, the public-private partnership model provides an advantage in that little or no direct public funding is required to implement and operate the scheme (little or no cost to the taxpayer). Indirect costs in the form of forgone advertising revenue still arise, however. Other operators include public transportation agencies, local authorities (e.g. cover costs using revenue from parking fees), for-profit companies and non-profit groups. ***Table 2.4*** provides an overview public-bicycle business models by type of operator. The operator is one of the four main stakeholder groups for bicycle-sharing schemes. The others are the politicians and planners, the users and the technology providers (if applicable).

Table 2.4: Overview of bicycle-sharing business models. Adapted from Midgley (2011) and Shaheen et al. (2010).

Provider	Model	Example
Advertising company	Provides and operates bicycle-sharing scheme in exchange for advertising rights and space (e.g. public toilets, bus shelters, billboards and public bicycles).	*Vélib'* (Paris, France)
Public transportation agencies	Provides and operates bicycle-sharing scheme to enhance public transportation services.	*Hangzhou Public Bicycle* (Hangzhou, China), *Call a Bike* (Germany)
Local authorities	1. Local authorities pay for bicycle-sharing scheme provided and operated by others.	*Bicing* (Barcelona, Spain)
	2. Local authorities design, own and operate bicycle-sharing scheme.	*Bike House* (Teheran, Iran)
For-profit	Provide and operate profitable bicycle-sharing scheme with minimal governmental involvement.	*StadtRAD* (Hamburg, Germany)
Non-profit	Provide and operate profitable bicycle-sharing scheme with the support of local authorities.	*Bycyklen* (Denmark)

2.4.1.5 WHO IS THE TYPICAL CYCLIST?

A study conducted in England by Gatersleben and Haddad (2010) examined the views people hold of the typical cyclist. In a questionnaire, respondents were asked to what extent 52 attributes (behaviours, motivations, personality and demographic characteristics) belong to the typical cyclist they see on their roads. The respondents tended to perceive four types of cyclists:

1. responsible cyclists;

2. lifestyle cyclists (who invest time and money into cycling);
3. commuters (professionals who cycle to work whatever the weather); and
4. 'hippy-go-lucky' cyclists who use their bicycles for everyday, non-work activities.

As the study was only undertaken in two towns in England, namely Norfolk and Surrey, the findings may differ from other parts of the country. Except for the responsible cyclist, a parallel was found in the types of cyclists identified by Jensen (1999) in Denmark, however. Among the six mobility types he identified, three related to cycling, namely

1. the cyclists of heart (who actively choose to cycle, because they enjoy it and realise the health benefits);
2. the cyclists of convenience; and
3. the cyclists of necessity.

According to Fishman *et al*. (2013), the literature reveals that the demographics of bicycle-sharing members are in contrast to those of the general population; the members have higher employment rates and education levels, a lower average age (persons in their twenties and thirties), and are more likely to be male. Carse *et al* (2013) confirmed these character traits in their investigation on the factors influencing private motor vehicle use in the bicycle-friendly city of Cambridge. They found driver participants to have a lower income, no degree level of education and be aged 40 to 49 or 60 years and older. Also, the higher the number of private motor vehicles available per adult in the household, the greater the likelihood that a trip would be made by this mode. Employment and a high education level generally imply auto ownership. For England and Wales it was found that the employees in households with a motor vehicle ownership count of one are more likely to cycle than employees in households with no motor vehicle (Parkin *et al*., 2007). But, at the level of two cars or more, the tendency to cycle was suppressed (Parkin *et al*.). Members of the bicycle-sharing scheme in Hangzhou also exhibited a higher rate of auto ownership than non-members (Fishman *et al.,* 2013). Furthermore, a negative correlation between docking station activity and the proportion of households without auto ownership was found in Washington, D.C. (Fishman *et al*.). This suggests that the inhabitants of these countries cycle out of choice and not economic necessity. According to McDonald (2012) the gender differences mentioned are only observed in countries where cycling is not the norm.

The lower bicycle-sharing adoption rates amongst those with a lower income and lower education level may be, at least to some extent, as a result of docking station location rather than an overall disinterest in bicycle-sharing. There might be an unmet demand for access to cycling in disadvantaged communities. In Santiago - the capital and largest city of Chile (a developing country) - a stated preference study found that young people, with low education levels and low income, and without a private motor vehicle in the household, were most willing to cycle (Parkin *et al*., 2007). In Greece, persons with a low income are more likely to become members of a bicycle-sharing scheme (Efthymiou *et al*., 2013). The typical user of the Delhi bicycle-sharing scheme is between 20 and 30 years old, male, and earns between INR[3] 2,000 and 10,000 (between ZAR 400 and 2,000) a month; 62.3% of the users are owners of a private motor vehicle (Dhingra & Kodukula, 2010). In Brazil, cycling is most apparent in cities with a population of less than 50,000, compared to middle and large-sized cities where public transportation systems are more developed (Jones & Azevedo, 2013).

Frequent recreational cycling does not inevitably lead to more frequent utility cycling, but many bicycle-sharing users do claim that recreational cycling encourages them to also cycle for utility purposes (Parkin *et al*., 2007). Moreover, bicycle-sharing members have a greater tendency to cycle

[3] The exchange rate from Indian Rupees (INR) to South African Rand (ZAR) was taken as 1 to 0.20, as on 22 August 2015.

independently of bicycle-sharing schemes. Some studies have discovered that bicycle-sharing schemes are used by those wishing to avoid theft of private bicycles (Fishman *et al*., 2013).

Lastly, employees in workplaces that encourage active travel are less likely to drive a motor vehicle to work (Webster & Cunningham, 2012), and the analysis of 90 large American cities publicised that cities with safer cycling facilities, lower auto ownership, more students, less urban sprawl and higher fuel prices had more residents cycling to work (Buehler & Pucher, 2012).

2.4.1.6 BENEFITS AND DISADVANTAGES OF CYCLING

For bicycle-sharing schemes to be accepted as an attractive mode of transportation, the bicycle must be able to compete with other modes of transportation for different types of journeys. This section converses the many benefits of cycling, but also identifies the drawbacks and preconceptions of this mode. Firstly, a list of the known cycling benefits is given, followed by a more detailed discussion of the benefits in terms of mobility, the economy, the environment and health.

According to De Waal (2000),

> *"it is irresponsible to ignore the benefits of bicycling".*

Garrard *et al*. (2012) argue that cycling projects tend to undervalued and undervalued, because it is difficult to quantify many of the cycling benefits and because the benefits are distributed across several sectors. The extent of the benefits is of course subject to the size of the bicycle-sharing network though, and also unique to each scheme. Benefits can be one of two types – direct benefits to the user or indirect benefits to society. Benefits subsequent to bicycle policies are either saved costs since bicycle trips are substituted for motorised trips, or benefits resulting directly from a rise in bicycle use. The list of known cycling benefits is as follows (the pros of bicycle-sharing schemes are also included):

- flexible mobility
- independent mobility / autonomy
- easy to move through dense urban environments
- reaches underserved destinations / accessibility improvements
- predictable trip duration
- solves last-mile problem
- cheap mode of transportation / individual financial savings
- reduced fuel use
- bicycle infrastructure is more cost-effective than standard investments made in urban transportation, such as building more roads, more parking spaces and flyovers (Dhingra & Kodukula, 2010).
- emission reductions – fulfil obligations towards environmental protocols
- reduced congestion; it is a non-congesting mode
- little noise pollution
- increase in environmental awareness by the user
- sustainable
- supports multimodal transportation
- physical activity / health benefits
- promotes psychological skills
- increase in neighbourhood connectivity
- decrease in demand for parking
- develops spatial and navigational skills in children, and stronger sense of community (Carver *et al.,* 2013)

- 'living streets' increase social interaction and reduces crime (Garrard *et al.*, 2012)
- less required space - in urban areas, bicycle lanes can accommodate 7 to 12 times as many people per metre of lane per hour than motor traffic lanes; and the space needed to provide 1 light motor-vehicle parking space can accommodate 12 parked bicycles (Flusche, 2009)

Bicycle-sharing schemes:

- highly adaptable to different types of cities and city sizes
- relatively quick installation / implementation
- overnight or long-term one-way trips possible without fear of theft

Before the hype of bicycle-sharing scheme came about, governments, interest groups and experts often undervalued the bicycle's contribution to well-being and prosperity (Buis *et al.*, 2000).

2.4.1.6.1 EFFECTIVE SPEED

"The car is assessed as being better than it really is, its alternatives worse",

says Werner Brög (Tranter, 2012). The concept of effective speeds helps one to realise why this statement is true when cycling is considered as the alternative mode of transportation. The formula for effective speed remains speed = distance / time, but with the modification that ALL costs are converted to time. The key trait of the effective speed concept is that it recognises that a significant time cost is time spent at work to earn the money required to pay for all the expenses associated with a specific mode of transportation. This falls under the direct cost, which comprises any time devoted to this mode (e.g. time spent at a petrol station filling up with petrol). When external costs are included in the calculation, these are, for example, accident costs, pollution and congestion; they make individuals responsible for the wider impacts of their travel behaviour.

The results of private effective speed calculations for motorists (direct costs only) in various cities, range from 18.3 km/h for Canberra in Australia to a mere 3 km/h for Nairobi, Kenya for all times of the day. For London and New York, the results were 8.4 km/h and 9.8 km/h, respectively. Including external costs, the range drops from 15.9 km/h (Canberra) to 2.2 km/h (Nairobi). To be faster than a small light motor vehicle (when external costs are ignored), cyclists would need to travel 21.5 km/h in Canberra and only 3.1 km/h in Nairobi. If external costs are included, cyclists in Canberra would need to travel only 18.3 km/h to exceed the speed of a motorist. Since the main time component for many motorists is the time spent earning the money to pay for the costs of private motor vehicles, increasing the travel speed has little effect on effective speeds. In fact, driving faster will likely reduce the effective speed, because it is associated with an increase in vehicle operating costs. In London, it was found that an increase in travel speed of 10 km/h would result in an increase in effective speed of only 0.7 km/h for motorists, but 8.7 km/h for cyclists.

(Tranter, 2012)

2.4.1.6.2 MOBILITY BENEFITS

Time lost in traffic congestion has economic consequences (i.e. an hour lost by an employee in a traffic jam is calculated as half of his / her average hourly wage (Buis *et al.* 2000)); time savings thus result in financial savings, and as a result, travel time plays a prominent role in the mode-choice decision-making process. A person on a bicycle can travel an average of four times further than a pedestrian, in the same stretch of time (Buis *et al.*). And, bicycles can measure up to the speed and flexibility of private motor vehicles on short journeys in many urban city centres (Romero *et al.*, 2012). In Copenhagen, time savings were noted for bicycle journeys of up to 5 km (Parkin *et al.*, 2007). In Greater Helsinki, the launch of a bicycle-sharing scheme was able to reduce public transportation travel times by more than 10% on average, which is equivalent to 6 minutes per individual trip (Jäppinen *et al.*, 2013). The results of a survey distributed in 2008 to *Vélib'* users showed that 89% of these bicycle-share users agreed that the bicycles make it easier to move around Paris (Shaheen *et al.*, 2012). Similar findings were observed for Washington, D.C., where 79% of the respondents reported that *SmartBike* use was faster and / or more convenient than other options (Shaheen *et al.*).

2.4.1.6.3 ECONOMIC BENEFITS

In congested areas, in addition to time savings and its associated cost savings, the bicycle also offers savings in travel cost. For each traversed kilometre, the travel costs for cycling are lower than for any other mode of transportation, with the exclusion of walking of course (Buis *et al.*, 2000). According to Flusche (2009), replacing a car trip with a bicycle trip saves individuals and society USD 2.73 per mile (ZAR 21.97 per kilometre). On average, Capital Bikeshare members save USD 800 (ZAR 10,360) yearly on travel cost (LDA Consulting, 2013).

When the economic value of investments in various modes of transportation is compared, bicycles are most victorious. The construction and maintenance of bicycle paths, and the construction of bicycle parking facilities, cost much less than roads and parking facilities for motor vehicles (Buis *et al.*, 2000). In Portland, United States, the city built its entire bicycle network for the cost of 1 mi (1.609 km) of urban freeway (Flusche, 2009). Investing in bicycle infrastructure produces savings in that bicycle paths require less space; and, per metre of road surface, bicycle routes accommodate a greater volume of traffic / persons than a roadway for motor traffic. Cycling and walking projects also create more jobs per ZAR than road projects, because they are labour-intensive and not materials-intensive (Flusche).

In the city of Dordrecht, the Netherlands, the cost of high-quality bicycle facilities was evaluated against the cost of widening the roadways. A situation developed in which the road widening was no longer required, because motor vehicle trips were replaced by bicycle trips. The cost of constructing new bicycle facilities (incl. four new bicycle tunnels), and improving existing bicycle facilities, e.g. parking facilities, amounted to just 75% of the cost of the road widening alternative. (Buis *et al.*, 2000)

The results of a study conducted in South Africa found bicycles to be of greater economic benefit than school buses as a mode of transportation to the 1.1 million school learners in the province of KwaZulu-Natal. The average travelling distance from home to a primary school is 3 km and from home to a high school is 5.5 km. Almost all learners walk to school, because other modes of transportation cannot be afforded. The majority of learners are hence often late or tired on arrival at school; 20% are absent. School buses were considered for half of the learners, with a one-way ticket costing ZAR 2.00 at the time; the total costs were computed as ZAR 432 million per year. If the government bought bicycles for the learners – for ZAR 500 each – to be used for five years, the total cost, including a ZAR 50 maintenance cost, came to ZAR 54 million per year, an annual saving of ZAR 378 million. (Buis *et al.*, 2000)

2.4.1.6.4 ENVIRONMENTAL BENEFITS

The transportation sector's contribution to environmental pollution varies from one country to the other. In addition to the difference in modal splits, fleet and total mobility of course, local fuel mixtures and engine technology play a role in this too. The vehicles in poorer countries are often older than, and not as economical as, those in wealthier countries. Many of these older vehicles are not fitted with catalysers and the fuel is not completely combusted. In 2000, Buis *et al.* conversed that pollution caused by motorised transportation leads to more deaths than traffic accidents. Garrard *et* al. (2012) regard premature deaths caused as a result of air pollution *"the silent road toll"*. Why is it then that motor vehicles are such a popular mode of transportation when their gaseous emissions and the vehicles themselves (i.e. accidents) are the cause of so many fatalities?

In most urban areas, motor vehicles are the leading source of pollution, and have high external costs with regards to energy consumption. More than half of the world's oil is supplied to the transportation sector. For motor traffic, the external costs are highest per motor-vehicle kilometre on short journeys in built-up areas. 30 to 60% of pollution from automobile emissions (particularly volatile organic compounds and carbon monoxide (CO)) occur in the first moments following 'cold starts', before pollution-control devices work effectively (Grabow *et al.*, 2010). Low speeds, and frequent acceleration and braking, also cause more pollution per kilometre for urban motorised journeys than long journeys. When accelerating and braking in the city, CO and hydrocarbon (CH) emissions are around 50% higher than when traffic is flowing at a constant rate. The nature of traffic flow has fairly little effect on NO_x emissions. Emissions of CO are approximately 50% higher for cold engines than when driving with a warm engine. Emissions of CH and NO_x from a cold engine are just about 10% higher from a warm engine (Grabow *et al.*, 2010).

Of all the emissions set off by motorised transportation, carbon dioxide (CO_2) is the most difficult to reduce, because catalysers have no effect. The only resolution is to use cleaner engines and travel less frequently. Cities with better modal shares of public transportation, walking and cycling, have notably lower per capita CO_2 emissions. In the Netherlands, CO_2 emissions from motor vehicles outside built-up areas (excluding motorways) are 36% less than inside built-up areas. For buses, the difference is 15%. Additionally, in spite of the below-average number of 14 passengers per bus, CO_2 emissions from buses in the Netherlands per travelled kilometre are still merely half those of light motor vehicle emissions.

In most cities, motorised passenger transportation is responsible for 70 to 90% of all CO emissions, and 30 to 50% of nitrogen oxide (NO_x) emissions. Urban transportation also causes smog and other forms of air pollution that are damaging to health. While the emission of lead by traffic in Western countries is hardly an issue anymore (the market has seen no new motor vehicles using leaded petrol for years), in non-Western countries, this remains a concern.

(Buis *et al.*, 2000)

Table 2.5 gives the emissions in grams per vehicle kilometre of four pollutants (CO, CH, NO_x and fine dust (PM10)), and clearly shows the effect travelling speed has on the emission quantities – the lower the speed, the higher the emissions.

Table 2.5: Emissions in grams per vehicle kilometre based on European averages. Adapted from Buis et al. (2000).

* Average for all speeds	CO	CO	CH	CH	NO_x	NO_x	PM10	PM10
** 45 kph, instead of 60 kph	20 kph	60 kph	20 kph	60 kph	20 kph	60 kph	20 kph	60 kph
Petrol light motor vehicle	17	6	2.9	1.1	1.8	2.5		
Petrol light motor vehicle (with a catalyst)	2.5	0.7	0.27	0.07	0.42	0.3	0.2*	
Diesel light motor vehicle	1	0.5	0.28	0.1	0.68	0.44	0.3	0.14
Urban bus	8.2	4.4**	0.21	0.1**	18	11**	0.85	0.32**
Moped	1.5*		0.9*		0.05*		?	

Cycling is a non-polluting mode of transportation and has a great potential in reducing urban pollution levels. If a cyclist makes a total of 160 annual bicycle trips of 3.9 km, this would equate to pollution-related savings of GBP[4] 69.14 (ZAR 1,406) a year if all previous trips were made by motor vehicle . (MacDonald, 2007). In rural areas, this value is much lower at GBP 12.98 (ZAR R264) a year with the same assumptions. (MacDonald). These numbers are dependent on the economic value that is assigned to the emissions, though, so these amounts are not directly transferable to South Africa.

2.4.1.6.5 HEALTH BENEFITS

The health risks associated with the pollutants discussed in the previous subsection (***Section 2.4.1.6.4)*** are summarised in ***Table 2.6***. The belief that cyclists inhale a higher quantity of harmful substances than motorists is not true. A study in Amsterdam showed that concentrations of CO, benzene, toluene and xylene in the air breathed by cyclists are, on average, three times lower than in the air breathed by motorists. The air breathed by cyclists does contain 25% more NO_2 though, when cycling on high-volume routes. (Buis *et al.*, 2000)

Table 2.6: The most significant health risks of substances emitted by motorised transportation. Adapted from Buis et al. (2000).

Substance	The harmful effect on health	Proportion of traffic in city centres, and other remarks
CO	- slows thought and reflexes	up to 90 to 95% of the total
	- causes drowsiness and headaches	
	- long-term exposure can lead to heart and vascular disease	
NOx	- irritation of lung tissue, which leads to increased susceptibility to viral infections, bronchitis and pneumonia.	up to 60 to 70% of the total
C_xH_x	- irritation of the eyes, coughing, sneezing and dullness	-
PM10	- affects function of the lung	up to around 50% of the total
	- premature death as consequence of respiratory and heart disease	
	- potentially carcinogenic	
Lead (Pb)	- impairs mental development in children, brain damage	up to 100%
	- high blood pressure	
	- kidney and liver damage	
Ozone (O_3)	- irritation of the eyes, cough and headache	formed by C_xH_x and NO_x
	- reduces lung function	
	- can exacerbate chronic heart disease, asthma and bronchitis	

In addition to the reduced exposure of cyclists to harmful substances, the energy expended by a person to wheel a bicycle forward results in noteworthy health benefits. Cycling for half an hour every day has a momentous impact on the prevention of heart and vascular diseases, breast and colon cancer, osteoporosis, stroke, diabetes, depression and anxiety, high blood pressure, and other illnesses. Additional benefits can be realised with up to an hour of total physical activity per day (Garrard *et al.*, 2012). Improved cognitive functioning and educational attainment have also been found among young

[4] The exchange rate from British Pound (GBP) to South African Rand (ZAR) was taken as 1 to 20.33, as on 22 August 2015.

individuals who partake in physical activity (Garrard *et al*.). Referring to US studies, Gerrard *et al*. report that

> *"… long-term regular physical activity was associated with significantly better cognitive function, less cognitive decline, improved motor function, improved memory, and a decreased risk of Alzheimer's disease".*

Research reveals that activities that become part of a person's everyday life (such as cycling to school / work), are more likely to be continued than activities that take time out of the day and require some form of attendance and commitment at specific venues; many urban commuters live such fast-paced lives that no time is available for physical exercise (Parkin *et al*., 2007). Furthermore, active transportation in adolescents promotes lifestyle patterns of physical activity that can be retained in adulthood (Yeung *et al*., 2008). The Dutch are closer to an average healthy weight nationally than people in other European countries (Buis et al., 2000); this can possibly be ascribed to the popularity of cycling in the Netherlands, as the Dutch carry out moderate-to-vigorous physical activity mostly in the form of cycling (Garrard *et al*., 2012).

According to the Comparative Risk Assessment of the World Health Organisation (WHO), sufficiently active persons *("at least 150 minutes of moderate-intensity physical activity or 60 minutes of vigorous-intensity physical activity a week")* reduce their *"risk of ischemic heart disease by 47%, risk of stroke by 39%, risk of breast cancer for women by 34%, risk for colon cancer by 43%, and risk for type II diabetes by 31%"* (Grabow *et al*., 2010). The level of physical activity is, in fact, exponentially related to the risk of developing major chronic diseases - the greater the level of inactivity, the higher the risk of developing major chronic diseases (MacDonald, 2007).

The consequences of physical inactivity are typically expressed in terms of monetary values. Costs due to physical inactivity and obesogenic environments can be reduced by promoting cycling. Physical inactivity costs the economy of England GBP 8.2 billion (ZAR 166.71 billion) a year, and obesity a further GBP 3.2 to 3.7 billion (ZAR 65.06 to 75.22 billion) (MacDonald, 2007). In addition, inactivity leads to higher health care expenses and absences from work. The former was calculated to be GBP 28.30 (ZAR 575.34) per inactive person per year, and the productivity that is lost through absence as an annual GBP 47.68 (ZAR 969.33) (MacDonald, 2007). Cavill *et al.* (2008) found reduced health costs associated with physical activity to be EUR 127 to 1,290 (ZAR 1,873 to 19,028) per new cyclist / walker (much of the variation is accounted for by dissimilar assumptions). The summary of the Nordic Councils of Ministers' report (2005) proposed that for public health benefits, the value of EUR 900 (ZAR 13,275) per year per activated person should be used, or EUR 0.15 (ZAR 2.21) per kilometre cycled (Cavill et al., 2008). In a cost / benefit analysis (CBA) of cycling networks in Norway, reduced health costs made up between two-thirds and one-half of the total benefits, which shows the substantial contribution health benefits make to BCRs (Garrard *et al*., 2012).

Jacobsen and Rutter (2012) make an important statement regarding the health benefits of cycling:

> *"that the health benefits to cyclists so consistently and greatly exceed the risks of being killed in a traffic crash needs to be prominent in any discussion of bicycle safety".*

They, furthermore, argue that

> *"… if minor injuries do not discourage physical activity, they represent primarily a financial cost and should not be considered a significant health issue".*

2.4.1.6.6 CASE STUDIES: OVERALL COST-BENEFIT ANALYSES

To give insight into how local differences give rise to dissimilar benefits in terms of increased bicycle use, Buis *et al*. (2000) carried out four cost-benefit case studies in cities from four different continents. The four cities were Amsterdam in the Netherlands (relatively small in size and high-income), Bogotá in Colombia (big and medium-income), Delhi in India (big and low-income) and Morogoro in Tanzania (relatively small and low-income). The bicycle modal splits at the time of the studies (for commuter transportation, not recreational purposes), were 28% for Amsterdam, 0.5% for Bogotá, between 7 and 20% for Delhi, and 20% for Morogoro. The calculated BCRs for the four cities (for different bicycle policies) were as follows:

- Amsterdam ("strong improvement of the 'core bicycle network' and citywide supply of high-quality bicycle parking facilities") = 1.5:1.
- Bogotá ("construction of a citywide bicycle network accompanied by education and promotion campaigns") = 7:1.
- Delhi ("reconstruction of a 9 km corridor to a road with bus lanes and bicycle tracks") = 20:1.
- Morogoro ("a citywide bicycle network accompanied by traffic calming measures") = 5:1.

In Amsterdam, where much had been done to promote cycling in the past already, it was much more challenging to increase the levels of cycling.

2.4.1.6.7 THE DRAWBACKS AND PRECONCEPTIONS OF CYCLING

The benefits of cycling are encouraging, but (as with all modes of transportation), cycling does have its drawbacks. The common disadvantages of cycling are as follows:

- can be uncomfortable in inclement weather (e.g. temperature extremes, high winds and precipitation)
- may be difficult to use in particular topography
- may be inaccessible to people with certain disabilities
- requires the user to have riding skills
- most appropriate for shorter distances
- traffic safety: users are more vulnerable on the road (opposed to in motor vehicles)
- personal security: more exposure to criminality
- difficulty carrying big and heavy loads
- some cyclists are inexperienced in cycling and do not obey by traffic laws (Midgley, 2011)

Whilst cycling has been widely accepted as a mode of transportation for all, preconceptions of cycling are not uncommon in the developing world. The three main preconceptions are that cycling is only for the poor; cycling is unsuitable for women; and somebody of high status should not cycle.

2.4.1.7 BARRIERS PREVENTING CYCLING

When bearing in mind the bicycle's widespread prospect in promoting sustainable mobility, its overall global modal share is rather dissatisfying. In 2013, 1% of all trip stages in England were made by bicycle, for example (Department for Transport UK, 2014). This is not so in all nations, however. In the Netherlands, for trips under 5 km, the modal share of bicycles is nearly 40% – the highest in Europe (European Commission, 2014). There are other countries too - such as China, Tanzania, Burkina Faso, Denmark, Germany, Italy, Peru and Cuba - in which the bicycle is an important mode of transportation and used for more than 20% of all urban journeys (Buis *et al*., 2000). As stated earlier in this document, it is implausible that bicycle-sharing schemes (on their own) will have a pronounced impact on cycling levels, because the cost of bicycle ownership and maintenance is not the main issue preventing the choice of cycling in urban peak-hour commute (Kumar *et al*., 2012). A vast number of other barriers prevent road users from undertaking the modal shift from the private motor vehicle to the bicycle, and it is of vital importance to recognise and comprehend these barriers before a bicycle-sharing scheme is designed, or worse implemented, as commuters will likely continue to drive (even if congestion is severe) until the barriers are addressed.

Gatersleben and Haddad (2010) found the common barriers to cycling to *be "… traffic safety, heavy traffic, inconsiderate drivers, pollution, bad weather, [far] distance and [long] travel time, [steep] gradient, not being fit enough and social pressure"*. Kingham *et al*., 2001 also state that there is simply too much traffic on the roads to cycle. Parkin *et* al. (2007) name other factors that are carefully considered by road users whilst contemplating a mode shift to cycling, namely: the amount of energy to be expended when cycling, perceived cycling ability, comfort, aesthetics, luggage handling and gearing of the bicycle, as well as the characteristics of the cycling environment (surface condition, general attractiveness of the route, and relative absence or presence of motor traffic). These, and other factors, are discussed in this section.

The bicycle-sharing schemes launched in Australia in 2010 (*CityCycle* in Brisbane, and *Melbourne Bike Share* in Melbourne), experiences usage rates much lower than originally anticipated, and as a result, many studies have been carried out to establish why this may be the case. Recent literature on the barriers preventing cycling is, therefore, mainly based on Australian data; but data for the United Kingdom and the United States are also available. In summary, it was learnt that the low Australian usage rates are due to a lack of accessibility / spontaneity (caused in part by a mandatory helmet legislation), overnight closure of the scheme, an inability to sign up easily with the swipe of a credit card, and safety issues (Fishman *et al*., 2013).

Bicycle commuting rates depend significantly on the supply of bicycle lanes and paths, i.e. bicycle infrastructure (Buehler & Pucker, 2012; Kingham *et al*., 2001). Of the *en route* bicycle facilities, a completely segregated bicycle path is predicted to have the greatest positive impact on the promotion of cycling (Wardman *et al*., 2007). Wardman *et al*. continue that a widespread provision of such facilities would only result in a 55% increase in cycling though and a slight decrease in private-motor-vehicle commuting, but would be highly effective if supplemented by financial incentives for cycling to work - a £2 daily payment almost doubles the level of cycling. (The monetary value would most likely have to be increased, however, as the success of £2 daily incentives is based on a 1997-study.)

Commuting distance is a key stumbling block in seeing a modal shift to cycling for the complete journey (Carse *et al*., 2013; Kingham *et al*., 2001), as many people live far from their place of work. Simply improving cycling infrastructure along the route will not solve this problem alone. Combining improved cycling infrastructure with a bicycle-sharing scheme (operating partially from a Park-and-Ride) enables the bicycle to, at least, form part of a multimodal journey, however.

The study conducted in Cambridge found that motor vehicle parking availability at the workplace is strongly associated with solo, private-motor-vehicle commuting (Carse *et al*., 2013). In the United States, it has been suggested that removing free or employer-paid parking could reduce private-motor-vehicle travel to work by up to 81% (Wilson & Shoup, 1990).

After the Olympic Games in 2008, Beijing faced a decline in the use of their bicycle-sharing scheme (Liu *et al*., 2012). Liu *et al*. elaborate on the cause of this decline. One of the reasons is the conflict between cyclists and traffic; another is that the city's bicycle-sharing scheme is operated by numerous rental companies that do not liaise. The demand has furthermore diminished due to the poor maintenance programme implemented over the years, i.e. the bicycles and associated equipment are in a bad condition. The rental fares are also unattractive; they are relatively high, and the deposits are often greater than the cost of a new bicycle. The operators request policy support and believe that the government needs to get involved in order to become successful in the future.

Four barriers are elaborated on in the following subsections, namely safety concerns, helmet laws, topography and climate, and social variables. The final subsection discusses how these barriers can be addressed.

2.4.1.7.1 SAFETY CONCERNS

"Cycling is a benign activity that often takes place in dangerous environments", say Jacobsen and Rutter (2012). The risk of severe injury while cycling is mostly imposed by motorists and not the activity of cycling itself. Of the barriers mentioned above, heavy traffic, inconsiderate drivers and the call for *en route* bicycle infrastructure all relate to concerns of safety, irrespective of cycling experience. This is because cyclists are highly vulnerable;

> *"bicycles do not benefit from cage construction, crumple zones or airbags"*

(Furth, 2012). When safety concerns are expressed, it is either actual safety or perceived safety (or both) that is referred to. Actual safety is based on statistics, while perceived safety denotes a person's subjective feeling of safety (Liu *et al*., 2012).

Worldwide, safety concerns are a major barrier to cycling and these concerns appear to greatly affect bicycle-sharing participation. Lack of cyclist awareness by motorists is a major issue, particularly for regular cyclists. Numerous instances of wilful disregard and the more common 'looked but did not see' were reported in both Brisbane and Melbourne (Fishman *et al*., 2012). The general perception of risk is influenced by the volume, speed and composition of traffic, and the number or parked vehicles, types of junctions and types of turns along the route (Parkin *et al*., 2007). A respondent of the *CityCycle* survey said,

> *"for novice riders, the traffic environment is a real turn off"*

(Fishman *et al*., 2012). Recreational cycling participation is often encouraged when the opportunity for traffic-free cycling presents itself; this situation is unfortunately rare in utilitarian-purpose cycling (Parkin *et al*., 2007). Whilst traffic-free routes may reduce the perceived hazard from traffic, a series of new problems may arise for the cyclists, namely:

1. conflict with pedestrians on shared-use paths,
2. lack of continuity of routes,
3. street furniture that creates obstacles on the pathway,
4. poor surfaces on off-road routes, and
5. off-road paths that take inconvenient routes, i.e. detours

(Parkin *et al*., 2007).

In Brisbane, study participants with an active *CityCycle* membership reported more impressive levels of consideration from drivers when cycling on a public rather than a private bicycle. Probable justifications for this phenomenon include that a public bicycle is still somewhat of a rare sight in Brisbane, and assumptions from the motorist regarding the low level of experience and skill of the bicycle-sharing user. (Fishman *et al*., 2013)

Using multiple regression analysis, a statistically significant relationship was found in Washington, D.C. between bicycle-sharing activity and the presence of bicycle lanes (Fishman *et al*., 2013).

Although there is a known correlation between the positive effects bicycle lanes have on private cycling, this is the first study to find such a correlation for bicycle-sharing schemes. In the United Kingdom, the provision of approaching bicycle lanes and through junctions was found not to significantly impact the perception of risk (Parkin *et al.*, 2007).

A synthesis of literature points towards parents emphasising children's safety at the expense of the development of their independence (Lorenc *et al.*, 2008). Both children and parents acknowledged the pressure on parents to fulfil their expectations of being 'good parents' - ensuring their children's safety at all times. Children viewed their parents' private motor vehicle use as limiting independence in the name of safety (Lorenc *et al.*, 2008).

Johnson *et al* (2014), Kumar *et al.* (2012) and multiple other studies (Webster & Cunningham, 2012) expect and report that as the number of cyclists in the population increases, the perception of safety of cyclists will increase, because more motorists will also be cyclists and therefore the awareness of cyclists by motorists will be more developed. This can be summarised into saying that the **safety in numbers theory** applies to cycling. A proof of the theory was founded in Paris. In 2001, the city's modal share of bicycles was only 1% of the 10.6 million daily trips, whilst from 2001 to 2006 this modal share increased to 48%, with no additional bicycle accidents or injuries (Dhingra & Kodukula, 2010). Buis *et al.* (2000) argue that this is only applicable to cities with remarkable bicycle facilities in place.

2.4.1.7.2 HELMET LAWS

Mandatory helmet legislation has emerged as a contentious issue in the field of bicycle-sharing, as it reduces the attractiveness of such schemes. Helmet regulations reduce the impromptu of a bicycle-sharing trip, because the inconvenience associated with carrying a helmet around all day, on the chance it may be required, is too great. Many people also simply do not want to wear a helmet, as proven in a study conducted in Melbourne, where 25% of the focus group did not want to wear helmets (Fishman *et al.*, 2013). Australia and New Zealand are the only two nations in the world with a federal helmet law for cycling that is enforced. In Japan and South Africa, the law is existent, but not enforced. In some other jurisdictions, partial laws apply (e.g. for children); for the rest, helmet laws have either been repealed (e.g. Mexico) or helmet wear is optional.

Since October 2004, it is mandatory for all cyclists in South Africa to wear a helmet, according to regulation 207(2) of the National Road Traffic Regulation.

> *"The regulation orders the compulsory wearing of a protective helmet that is properly fastened and fitted while riding a bicycle or being carried as a passenger."*

According to *Arrive Alive*, the law is not enforced in practice, as the government could not agree on how to enforce it. As a result, few cyclists wear helmets in South Africa, except those participating in the sport of cycling. Most bicycle race organisers apply the law with a "no helmet, no ride" policy.

The rental of helmets to the users of public bicycles (either by the scheme organisation or a local bicycle store) raises hygienic issues (perspiration and lice (Fishman *et al.*, 2012)), as well as liability issues in the case of defective or lost helmets (DeMaio & Gifford, 2004). Members of *CityCycle* did not share the concerns regarding perspiration; according to them, the duration and intensity of a typical *CityCycle* ride is not sufficient to perspire (Fishman *et al.*, 2012). Members who had begun to use the helmets distributed by the *CityCycle* operators through the use of vending machines, remarked that the bicycles with helmets were usually *"the first to go"* (Fishman *et al.*, 2012).

In a study conducted in Washington, D.C. in October 2011, it was found that helmet use was significantly lower among cyclists on shared bicycles than private bicycles (Kraemer *et al.*, 2012).

Another study (independent of the first) made the same observations for Boston and also Washington, D.C., with the ratio of unhelmeted bicycle-share users to unhelmeted users of personal bicycles being 1:0.6 (Fisher *et al.*, 2012). Even more bicycle-share users are unhelmeted on weekends. A probable explanation is that helmets are not provided (for purchase or rent) at the rental kiosks (Fisher *et al.*, 2012).

Although the bicycles are designed with safety in mind, the risk of injury still increases for unhelmeted cyclists in the event of a crash (Kraemer *et al.*, 2012). Helmets decrease the risk of head and brain injury by 65 to 88% (Fisher *et* al., 2012). Furthermore, head injuries make up circa one third of all bicycle-related injuries, and almost three quarters of all bicycle-related fatalities (Fisher *et al.*, 2012). The helmet dilemma needs to be resolved so that neither safety, nor spontaneity is sacrificed. It should be noted, however, that helmets do not create safety;

> *"only a safe environment, free from the dangers created by motorised traffic and poorly designed roads, can do that"*

(Jacobsen & Rutter, 2012). Jacobsen and Rutter add that recent studies have surprisingly found much lower estimates of the protective effects of helmets to head, neck and facial injuries.

Public awareness campaigns, sponsored public outreach programmes, and subsidised or free helmets, have shown to moderately increase helmet-wear rates amongst children; their effectiveness when targeting adults is unknown (Fisher *et al.*, 2012).

2.4.1.7.3 TOPOGRAPHY AND CLIMATE

Cyclists generally dislike gradients of more than +4%, and avoid gradients greater than +8% (Midgley, 2011). Topography thus becomes a limiting factor to cycling when the gradient of the incline falls between +4% and + 8%. A 10% increase in hilliness is coupled with a 10 to 15% decline in the number of persons cycling to work (Parkin *et al.*, 2007). As is the case in Barcelona, cyclists will cycle down a slope, but will refuse to cycle back up, and use another mode of transportation for the return trip. As a result, bicycle-sharing stations at high-level elevations tend to empty, while the lower-level stations tend to fill up. Cycling up steep slopes means that the amount of energy expended is greater and consequentially perspiration too increases. This brings about an additional barrier – no shower access at the final destination.

According to Midgley (2011), bicycle-sharing schemes have been successfully implemented in cities with very dissimilar climatic conditions. In 90 of the United States' large cities, annual precipitation and the number of hot and cold days are not statistically significant forecasters of bicycle commuting (Buehler & Pucher, 2012). Some work seems to point in the opposite direction for other countries, however. Precipitation, temperature and humidity have both immediate and lagged effects on daily usage rates in Melbourne (Lathia & Capra, 2012), and according to Kumar *et al*. (2012), data suggests a significant decline in bicycle usage when it is cold (<5 °C) or when it is hot and humid (>28 °C and 60% humidity). In Northern Europe, most schemes, in fact, tend to close during the colder winter months, while the rest remain open all-year-round (Midgley, 2011).

2.4.1.7.4 SOCIAL VARIABLES

Social variables, such as social identity, social norms and stereotypes, have received little attention in the research of cycling and the barriers to public-bicycle use. According to Gatersleben and Haddad (2010),

> *"social science research has shown that the stereotypes people hold of social groups can influence their perceptions, attitudes and behaviour. … If people hold negative stereotypes*

of the typical cyclist, or if they hold views that include uncommon characteristics and behaviours, they may be less likely to take up cycling or to be influenced by cycling information campaigns".

The **social identity theory**, proposed by Henri Tajfel in 1979, states that people are likely to view the in-group (to which they feel they belong) more positively than the out-group (to which they do not belong). The findings of the study by Gatersleben and Haddad, referred to in ***Section 2.4.1.5***, were that the respondents who had recently used a bicycle tended to perceive the typical cyclist as someone that uses a bicycle for normal everyday activities, such as shopping and commuting. The respondents who had not cycled in a while (or ever) were more likely to view the typical cyclist as a lifestyle cyclist, someone who cycles for leisure pursuit and invests a lot of time and money into cycling. Under the social identity theory, the views of the cyclists are most likely optimistic and the views of the non-cyclist pessimistic. If cycling is seen as an activity exclusive to a small group of interested people, and not as something that can be encompassed into the daily-life routine, this can be a major barrier to the anticipated increase in cyclists and bicycle trips.

Motorists tend to have a negative perception of cyclists, and view them as an out-group with characteristics significantly different from most other road users and the social norm (Basford *et al.*, 2002). The unpredictability and seemingly inherent 'different' behaviour of cyclists bring about an element of road rage in motorists, especially when the conduct of the cyclists comes to the detriment of the motorist. It is highly unlikely in such a case that motorists will leave the comfort of their in-group to make a modal shift to the out-group.

On the one hand, cyclists themselves do not promote the mode of cycling well (motorists do not want to become cyclists); but on the other hand, the erratic driving behaviour of motorists intimidates potential cyclists and prevents them from cycling as a result. The behaviour of both the cyclist and the motorist are thus barriers to cycling.

2.4.1.7.5 ADDRESSING THE BARRIERS

The respondents of a Greek study list the most important factors affecting car- and bicycle-sharing adoption (in decreasing order) as: *"distance of* [car- or bicycle-sharing] *station from home or work; ability to return the vehicle / bicycle to another station; ability to return the vehicle / bicycle without previously informing the centre about the time and station; time of day (e.g. day / night); reservation process; available type of vehicle / bicycle"* (Efthymiou *et al.*, 2013). Several of Brisbane's non-*CityCycle* members commented that docking stations would need to be placed closer to their homes and workplace, and integrated better with public transportation for them to consider a mode change to public bicycles. The most effective policy to encourage cycling, according to Wardman *et al.* (2007), combines improvements in *en route* facilities, a daily payment to cycle to work, and acceptable trip-end facilities. Kumar *et al.* (2012) also state that high bicycle modal share can only be achieved and sustained with a safe, extensive and continually improving cycling infrastructure; bicycle-friendly intersections and widespread traffic calming are also of assistance. (For cycling infrastructure see ***Section 2.4.2.4****)*. Whilst previous studies have found a strong correlation between the number of bicycle lanes per square mile and bicycle usage (Dill & Carr, 2003), the study by Buehler and Pucher (2012) was the first to differentiate between bicycle lanes and bicycle paths; they found neither to be more favoured in general.

A provincial step towards providing safer cycling across the Western Cape was made in 2013, when the 1-m passing law was written into the Western Cape statute books. The new provincial regulations require a motor vehicle driver to keep a distance of at least 1m between the motor vehicle and the cyclist, and maintain this distance until safely clear of the cyclist. But, there is doubt by cyclists, that motorists will obey the law (Williams, 2013). In several American states, this buffer is 3 feet by law.

Cost-benefit calculations performed for various traffic safety measures using European data show that measures for cyclists and pedestrians result in high BCRs. The BCRs of three such safety measures are given below.

1. Speed restrictions in urban areas reduce the mean risk of a cyclist / pedestrian accident by over 50%; the BCR is 9:1.
2. Segregated bicycle paths are of benefit to motor-vehicle drivers, cyclists and also traffic flow; here too the BCR is 9:1.
3. Giving right of way to cyclists at traffic intersections by means of an advanced stopping line over the full width of the road, decreases the probability of an accident from occurring; the BCR is 12:1.
   (Buis *et al*., 2000)

With such a long and diverse list of barriers and measures of addressing them best, it is important to conduct a comprehensive study that identifies the barriers specific to the town or city for which a bicycle-sharing scheme is considered. Furthermore, it seems logical that the most profitable approach to enhance cycling is likely to be a compilation of measures that contain a range of cycling stimuli addressing the identified barriers. Educating drivers and cyclists on the bicycle laws and cycling etiquette could also prove to be valuable.

2.4.1.8 SUSTAINABILITY – SHIFTING FROM PRIVATE MOTOR VEHICLES TO BICYCLES

With the benefits of cycling as mentioned in ***Section 2.4.1.6***, this mode of transportation has emerged as an increasingly common response to overcoming the challenges of private-motor-vehicle dependence. According to Fishman *et al*. (2013),

> *"… the establishment of bicycle-sharing schemes has prominently enabled cities to demonstrate their commitment to addressing climate change, population health issues, traffic congestion, oil dependence and liveability".*

Whilst the objectives of bicycle-sharing are promising, the assumption that a significant proportion of users transfer to bicycle-sharing schemes from single-occupant private motor vehicles appears to be an optimistic assumption. In fact, it is more common for the majority of bicycle-sharing trips to be substitutes for other sustainable modes of transportation such as walking, personal bicycles and / or public transportation (Midgley, 2011). As a result, estimates of numerous bicycle-sharing benefits, such as CO_2 and congestion reductions, are exaggerated. For Barcelona, Lyon, Montreal and Paris, the percentage of motor vehicle trips replaced by bicycle-sharing trips ranged between 2 and 10% in 2008 (Midgley, 2011). In Dublin, London and Washington, D.C., bicycle-sharing schemes have reported similar low transfer rates from the motor vehicle to the public bicycles (Fishman *et al*., 2013). If *Capital Bikeshare* was not available in Washington, D.C., only 7% of the trips made by public bicycle in 2011 would have been made by private motor vehicle (Fishman *et al*., 2013). For Minnesota the value was higher, at 19.3%. China falls out of this norm, however. Four out of five light motor vehicle owners (majority of the bicycle-sharing members) proclaimed that they used the public bicycles for trips for which the motor vehicle would have been used normally (Fishman *et al*., 2013). The results of another comprehensive study (10,661 respondents to an online survey), conducted in North America (Montreal, Toronto, Washington, D.C. and Minneapolis) in 2012, were consistent with previous findings, showing that mode substitution from private motor vehicles to bicycle-sharing is low (Shaheen *et al*., 2012). In

South Africa, however, few alternatives to the private motor vehicle are available to commuters, and hence bicycle-sharing users are more likely to have been motorists in the past.

2.4.1.9 AVERAGE ACCEPTABLE CYCLING DISTANCE

Midgley (2011) says that people are willing to walk up to 10 minutes, and that most cycling distances normally fall within the range of 1 to 5 km. In most European countries, the average trip length for cycling is around 3 km (European Commission, 2014), whilst a distance of up to 10 km can be traversed within a time frame of 30 minutes (Parkin *et al*., 2007). It is proclaimed that in London, a cycling distance of 1 to 8 km is considered to be time-competitive with all other modes of transportation (Transport for London and the Clear Zones Partnership, 2008). Nelson *et al*. (2008) state that distances within about 4 km are achievable by adolescent walkers and cyclists. All things considered, the acceptable cycling distance is dependent on the age, fitness and cycling skills of the individual cyclist, and whether the bicycle is a choice or a captive mode of transportation.

2.4.1.10 USAGE RATES

Substantial differences exist in the usage of bicycle-sharing schemes worldwide. The usage rates vary between three and eight trips per bicycle per day (Fishman *et al*., 2013). Annual average usage rates are rarely reported on, as the seasonal differences are too high. As mentioned in ***Section 2.4.1.7***, the bicycle-sharing schemes in Melbourne and Brisbane have significantly lower usage rates; their rates are circa 0.3 to 0.4 trips per bicycle per day (Fishman *et al*., 2013). Interestingly, in London and Lyon bicycle-sharing usage increases have been reported in the event of public transit disruptions, such as strikes (Fuller *et al*., 2012).

2.4.1.11 USER TARIFFS

Pricing structures for bicycle-sharing schemes generally encourage short-term rental and are time-dependent; the first 30 minutes are usually free – increasing the likelihood that stations will have ample bicycles available. After the free-time, users are charged on an exponential scale. Many schemes, such as *Vélib* and *Capital Bikeshare*, have multiple pricing plans for its users, keeping in mind possible usage needs. In most cases, a once-off access fee is charged plus a usage fee should the trip be longer than 30 minutes. The tariffs of ten bicycle-sharing schemes, namely *Santander Cycles* (London), *BIXI* (Montreal), *Call a Bike* (Germany), *Bycyklen* (Copenhagen), *Capital Bikeshare* (Washington, D.C.), *CityCycle* (Brisbane), *Greenolution* (Delhi), *Hangzhou Public Bicycle Service* (Hangzhou), *OV fiets* (the Netherlands), *Up Cycles* (Cape Town) and *Vélib'* (Paris), are compared in ***Table 2.7***. ***Table 2.8*** is a copy of ***Table 2.7***, but with the difference that all values have been converted to values in ZAR. At the bottom of ***Table 2.8*** the fees for scholars and students, for example, who use the bicycles for 200 days of the year for trips of less than 30 minutes are compared. After *Hangzhou Public Bicycle Service* and *Greenolution*, *Vélib'* and then *CityCycle* have the cheapest tariffs and hence the most suitable pricing structures for usage of such a nature. The importance bicycle-sharing users place on 'value for money' appears dominant in their motivation to sign up and use the system (Fishman *et al*., 2013). A compromise between attracting more users and keeping the bicycles secure is thus often made by the operator.

2.4.1.12 MULTIMODAL CONNECTIVITY

Bicycles and public transit have traditionally been seen as competitors, and the potential for cooperation has largely been ignored (Jäppinen *et al*., 2013). Combining bicycle-sharing schemes and public transit (either a bus service or metro system) in a multimodal transportation system presents

Table 2.7: Access and usage fees of ten cities.

	Santander Cycles	**BIXI**		**Bycyklen**		**Call a Bike**		**Capital Bikeshare**	**CityCycle**	**Greenolution**	**Hangzhou Public Bicycle Service**	**OV fiets**	**Vélib'**	**Up Cycle**
City	London	Montreal		Copenhagen		several cities in Germany		Washington, D.C.	Brisbane	Delhi	Hangzhou	the Netherlands	Paris	Cape Town
Currency	GBP	CAD		DKK		EUR		USD	AUD	INR	CNY	EUR	EUR	ZAR
		members	casual users	members	casual users	BASIS	KOMFORT							
Access Fees														
one way			$2.75								Once-off fee of ¥ 25 for an IC card, and a ¥ 200 deposit. ¥ 0.50 per month maintenance fee (until deactivation of IC card)			
1 day	£2		$5					$8	$2				1.70 €	
daily	£2		$5					$10 + $7/day	$2				1.70 €	
3 days			$12					$17						
7 days													8 €	
1 month		$30		70 kr			7 € to 9 €	$28						
3 months									$27.50					
6 months for students									$27.50					
1 year		$85				3 €	39 € to 49 €	$85 to $96	$45 to $60.50			10 €	19 € to 39[1] €	
Usage Fees														
First 15 min					25 kr per hour or part thereof.	1 € per half-hour or part thereof.				₹10 per hour or part thereof.		FREE		
First 30 min	FREE		FREE	FREE			FREE	FREE	FREE			3.15 € per 24-hours until 72 hours. Thereafter 5 € per 24-hours. plus 10 € if returned to a different station.	FREE	
First 45 min	£2 per half-hour or part thereof (max. hire of 24 hours).	FREE					1 € per half-hour or part thereof.							
Up to 1 hour		$1.75	$1.75	6 kr per hour or part thereof.				$2 or $1.50	$2.20		FREE		1 €	R50
Up to 1 hour 30 min		$3.50	$3.50					$6 or $4.50	$6.05				2 €	
Up to 2 hours		$7 per half-hour or part thereof until 24 hours.	$7 per half-hour or part thereof until 24 hours.					$14 or $10.50	$11		¥ 1		4 € per half-hour or part thereof until 24 hours.	R80
Up to 2 hours 30 min								$22 or $16.50						
Up to 3 hours								$30 or $22.50	$19.80		¥ 3			R120
Up to 4 hours											¥ 3 per hour or part thereof.			
Up to 5 hours									$38.50					
Up to 6 hours														
Up to 6 hours 30 min								$8 or $6 per half-hour.						
Up to 7 hours														
Up to 8 hours														
Up to 9 hours														
Up to 10 hours									$77					
Up to 12 hours (half day)														R150
Up to 24 hours						max. 12 € to 15 € per day.	max. 9 € to 12 € per day.	$94 or $70.50	$165					R200

[1] first 45 min are free.

Table 2.8: Access and usage fees of ten cities (converted to ZAR).

	Santander Cycles	BIXI		Bycyklen		Call a Bike		Capital Bikeshare	CityCycle	Greenolution	Hangzhou Public Bicycle Service	OV fiets	Vélib'	Up Cycle
City	London	Montreal		Copenhagen		several cities in Germany		Washington, D.C.	Brisbane	Delhi	Hangzhou	the Netherlands	Paris	Cape Town
		members	casual users	members	casual users	BASIS	KOMFORT							
Access Fees														
one way			R27.01											
1 day	R40.66		R49.10					R103.60	R18.96				R25.08	
daily	R40.66		R49.10					R129.50 + R90.65/day	R18.96		Once-off fee of R50.75 for an IC card, and a R406 deposit.		R25.08	
3 days			R117.84					R220.15						
7 days													R118	
1 month		R294.60		R138.60			R103.25 to R132.75	R362.60						
3 months									R260.70					
6 months for students									R260.70		R1.02 per month maintenance fee (until deactivation of IC card)			
1 year		R834.70				R44.25	R575.25 to R722.75	R1100.75 or R1,243.20²	R426.60 to R573.54			R147.50	R280.25 to R575.25³	
Usage Fees														
First 15 min												FREE		
First 30 min	FREE		FREE	FREE			FREE	FREE	FREE				FREE	
First 45 min		FREE												
Up to 1 hour		R17.19	R17.19					R25.90 or R19.43	R20.86		FREE		R14.75	R50
Up to 1 hour 30 min		R34.37	R34.37					R77.70 or R58.28	R57.35				R29.50	
Up to 2 hours								R181.30 or R135.98	R104.28		R2.03			R80
Up to 2 hours 30 min								R284.90 or R213.68						
Up to 3 hours								R388.50 or R291.38	R187.70		R6.09	R46.46 per 24-hours until 72 hours. Thereafter R73.75 per 24-hours.		R120
Up to 4 hours						R14.25 per half-hour or part thereof.								
Up to 5 hours					R49.50 per hour or part thereof.		R14.25 per half-hour or part thereof.		R364.98	R2 per hour or part thereof.				
Up to 6 hours	R40.66 per half-hour or part thereof (max. hire of 24 hours).			R11.88 per hour or part thereof.										
Up to 6 hours 30 min		R68.74 per half-hour or part thereof until 24 hours.	R68.74 per half-hour or part thereof until 24 hours.					R103.60 or R77.70 per half-hour.					R59 € per half-hour or part thereof until 24 hours.	
Up to 7 hours														
Up to 8 hours											R3.09 per hour or part thereof.			
Up to 9 hours												plus R147.50 if returned to a different station.		
Up to 10 hours									R729.96					
Up to 12 hours (half day)														R150
Up to 24 hours						max. R177 to R221.25 per day.	max. R132.75 to R177 per day.	R1217.30 or R912.98	R1564.20					R200
														²monthly instalments, ³first 45 min are free.
Fees for 200 days per year (assuming a ride of <30min)	R8,132	R834.70		R1,663.20		R575.25 (student fee)		R1100.75	R426.60 (student fee)	R400	R468.99 (incl. deposit)	R9,439.50	R280.25	R10,000

opportunities to capitalise on the strengths of both systems while avoiding their weaknesses. Because of its ability to provide seamless connections, this combination thus becomes a competitive alternative to private motor vehicles. Ultimately, a high level of long-term sustainable mobility is achieved. Also, the last leg of a journey that was previously completed by transferring to another transit vehicle may now be completed by bicycle - an 'extension service'-, which could ultimately result in a time saving due to inadequate timetables or at least be perceived as a time saving, because

> *"…trip time associated with waiting for or transferring to a transit vehicle is perceived to be two to three times as onerous as the actual travel time"* (DeMaio & Gifford, 2004).

In cases where the last-mile was formerly completed on foot due to poor network coverage, obvious time savings can be achieved with the use of a public bicycle. In cities with adequate and efficient public transit, the integration of public transit and bicycle-sharing schemes has become prevalent worldwide; bicycle-sharing docking stations are present at almost all major public transit stations/stops. In China, for example, the integration to the metro system is an important role of the bicycle-sharing scheme, with 58.4 and 55% of respondents linking these two modes, in Beijing and Shanghai respectively; in Hangzhou there is an integration to the extensive bus network. Research from Melbourne that analysed the activity and trip patterns across the bicycle-sharing scheme, found a strong correlation between the activity at docking stations and the proximity to train stations. This relationship was most apparent during the peak hour. Given the peak-hour congestion users are subjected to on many urban public transit systems, bicycle-sharing schemes may act to lessen public transit overcrowding. (Fishman *et al*., 2013)

2.4.1.13 TRIP PURPOSE

A survey distributed to the members of *Capital Bikeshare* in Washington, D.C. found the most commonly named trip purposes to be social / entertainment and errands / personal appointments (Fishman *et al*, 2013). Not surprisingly surveyed, was the fact that members without auto ownership used the bicycle-sharing scheme for a greater variety of trip purposes. Similarly, respondents without a private bicycle used the scheme more for the purpose of exercise / recreation. (Fishman *et al*., 2013). For the study conducted by Shaheen *et al*. (2012) in North America, for four of the continent's largest bicycle-sharing schemes (Montreal, Toronto, Washington, D.C. and Minneapolis) in 2012, travel to / from work was the most popular trip purpose. It seems logical that annual members are more likely to use public bicycles for regular, non-recreational journeys, whereas daily pass holders tend to use the scheme more for leisure / recreational purposes (Shaheen *et al*., 2012).

In the Chinese bicycle-sharing capitals of Beijing, Hangzhou and Shanghai, significant differences in trip purposes were noted. In Beijing, just about 45% of respondents use the bicycle-sharing scheme for trips to work, compared to around 18% for both Hangzhou and Shanghai. More than 50% of the Shanghai respondents reported using public bicycles for the return-from-work trip, compared to 29 and 23% in Beijing and Hangzhou, respectively. Hangzhou respondents usually used the public bicycles for a greater variety of trip purposes than respondents from Beijing and Shanghai. (Fishman *et al*., 2013)

It is evident that trip purposes greatly vary from one city to another. Trip purpose is dependent on access to other public and private modes of transportation, and of course also on a range of external influences.

2.4.1.14 REDISTRIBUTION

A key dilemma of bicycle-sharing schemes is that on arrival of a user, stations may be either empty, or full in the case of wanting to return a bicycle. With all the commuting, bicycles inevitably become concentrated in some areas of the city, whilst other parts have limited fleet availability (e.g. users cycle downhill into the city, but return uphill with the bus, as described for Barcelona in ***Section 2.4.1.7.3)***. This makes the service unreliable. Rebalancing means that an operator (with a fossil-fuelled vehicle) has to continually move around the network to maintain a more even distribution across the various docking stations. Forecasting distribution patterns is complex and the rebalancing itself is financially demanding. The operation can furthermore threaten the environmental credibility of the bicycle-sharing scheme. Suggested, and in some instances employed, solutions that reduce the extent of the problem mainly comprise offering rewards to users who cycle against the flow.

2.4.1.15 MAINTENANCE

Most schemes have at least one dispatch vehicle that is used as a mobile repair station for bicycles that require fixing. On-ground teams go from one station to another to locate any bicycles in need of maintenance. Bicycles are fixed on the spot where possible, but are otherwise taken to a repair centre with professional technicians when major repair is required.

2.4.2 THE COMPONENTS OF BICYCLE-SHARING SCHEMES

2.4.2.1 MANUAL AND AUTOMATED SYSTEMS

Bicycle-sharing schemes are classified as one of two types: manual or automatic. A manual bicycle-sharing scheme is one where check-ins and check-outs are supervised by staff (a manned bicycle station). Manual schemes may, but do not necessarily, involve technology for tracking the use of bicycles and associated monetary transactions. In an automatic bicycle-sharing scheme, check-ins and check-outs are unsupervised (unmanned) – they rely on self-service (with the identity of the user known). Here, the bicycles are either locked to electronically controlled racks, or are equipped with an electronically controlled lock of their own. Automated schemes rely heavily on technology for user interface, system control and monitoring. (Midgley, 2011)

The New and Innovative Concepts for Helping European Transport Sustainability (NICHES) consortium suggested that a population of at least 200,000 is required to support an automatic bicycle-sharing scheme (Midgley, 2011). ***Table 2.9*** illustrates the recommended type and scale of bicycle-sharing schemes relative to the city size and density. The theoretical bicycle-sharing scheme for

Table 2.9: Recommended type and scale of bicycle-sharing scheme relative to city size and density. Adapted from Transport Canada (2009).

City population	Density	System type	Distribution
> 200,000	high	automatic	throughout the city
	low	automatic	in the city centre or high density areas
50,000 to 200,000	high	automatic	throughout the city
	low	manual	at public transportation stations and public facilities
< 50,000	high	automatic	at main activity centres (main public transportation stations, commercial centres, health centres, etc.)
	low	manual	at public transportation stations and public facilities

Stellenbosch is not intended for the whole population, so the numbers in this table are not valid.

2.4.2.2 DOCKING STATIONS

Docking stations are typically located 300 m apart. ***Table 2.10*** provides a summary of the different types of docking station mechanisms available. (Their accompanying locking technologies have been discussed in ***Section 2.4.1.2***.) As said, flex stations (also referred to as the free-placement model), are used by Deutsche Bahn, but are otherwise not liked very much and are rarely employed. Fixed-portable stations allow for the transfer to different locations according to user demand. Fixed docking stations are composed of two basic components: a service terminal and bicycle locking stands. A standard service terminal is characterised by the following five elements:

1. **Advertising space**
2. **Touch sensitive screen** – provides a user interface for performing basic financial transactions,
   and providing information on how to use the system and about the availability of bicycles and docking spaces at other stations.
3. **Key card reader (validator)** – for users with long-term memberships.
4. **Financial card terminal** – accepts credit and debit cards for the purchase of temporary passes.
5. **Card dispenser** – dispenses temporary passes purchased at the terminal.

Software is also needed to operate the scheme at the back- and front-end. A further key consideration in terms of equipment choice is the type of power supply that will be made use of to operate fixed stations – either alternating current (AC) hardwired into the power grid, or solar power. The type of

Table 2.10: Analysis of different docking mechanisms.
Adapted from Transport for London and the Clear Zones Partnership (2008) and Transport Canada (2009).

	How does it work?	Strengths	Weaknesses
Fixed-permanent	Fixed 'posts' to which the bicycle is attached. Stations are hardwired to electricity mains and IT cables.	Easy to locate, a visible sign of the location of stations and the extent of the scheme.	Expensive and relatively inflexible.
Fixed-portable	Hire stations are equipped with cables (attached to a wall or existing bicycle stand), which are attached to the bicycle when docked. Bicycles are taken out and returned by use of telephone and pin code.	Able to accommodate up to ten bicycles in a single car parking space (compared to four with the fixed system).	Bicycles are prone to falling over and being regarded as untidy of the streetscape.
Flexible	Bicycles are self-locking; a metal pole is locked through the spokes. The bicycle is then left in a specific area and accessed by telephone and pin code.	Extremely flexible and convenient for the user once he or she has accessed a bicycle.	Difficult to find bicycles and the system relies on trust in terms of returning bicycles and communicating to the system the location of a returned bicycle.

power supply impacts total capital costs. Solar panels tend to be more costly to deploy, but can eventually prove to be more cost effective; AC-powered stations require additional infrastructure, and are not as flexible in terms of location.

2.4.2.3 THE BICYCLES

The bicycles of bicycle-sharing schemes – utility bicycles, or also termed transport, normal, Dutch or town / city bicycles – generally have a unique, perceptible appearance. Bright fluorescent colours as well as reflectors, and front and rear lights are employed to make it distinguishable. The bicycles are furthermore designed to be easy to use, strong and easy to maintain, comfortable (adaptability to users of different heights), green (produced with minimal environmental impact, using durable material that can be repaired and recycled), safe (automatic lighting, strong reliable breaks, and upright riding position that improves the ability to see traffic) and practical (provision for luggage and large cargo). (See ***Figure 2.8*** for the features of a typical bicycle-sharing bicycle). The bicycles also allow the user to wear everyday clothing – clothing that the users would normally wear to their intended destination. To limit vandalism, the bicycles are designed of a robust and vandal- proof nature. They are usually built with puncture-proof tyres, a strong frame and an adjustable seat post. The components are designed to be of uncommon dimensions and require special tools for disassembly (DeMaio & Gifford, 2004). Their unique appearance also discourages theft.

- unisex
- distinctive appearance
- adjustable cushioned saddle
- upright geometry / riding position
- robust and vandal-proof
- strong, step-through frame
- puncture-proof tyres
- uncommon dimensions
- require special tools for disassembly
- non-slip handlebars
- self-generating front and rear lights
- reflective strips on wheels and pedals
- front and rear brakes
- pedal brakes
- enclosed, stainless steel all-weather chain
- resistant locking system
- finger touch bell
- kick stand
- front and rear mud guards
- baggage capacity
- low centre of gravity
- fitted with RFID (Radio Frequency Identification)

Figure 2.8: Features of a typical bicycle-sharing bicycle.

2.4.2.4 CYCLING INFRASTRUCTURE

"A bicycle path is a social statement that a person with a $40 bicycle is as important as anyone with a $40,000 car." (Peñalosa in Gerrard *et al*., 2012). The Dutch cycling design guidance, which addresses

the barriers that frequently prevent bicycle use, identifies the fundamental infrastructure requirements for cycling. Bicycle infrastructure should be:

- *"**coherent / comprehensive**: a comprehensive network linked to where cyclists begin and end their journeys;*
- ***direct**: a system of connections, which is as direct as possible and avoids detours;*
- ***attractive**: design and integration with surroundings should make it pleasant to cycle;*
- ***safe**: facilities that guarantee safety from other road users and take account of personal security as well as road safety; and*
- ***comfortable**: facilities that allow a rapid and comfortable flow of bicycle traffic".* (Parkin *et al.*, 2007)

From the discussion in ***Section 2.4.1.7.1***, one can deduce that safety is achieved by making certain that low conflict exists between cyclists and motor vehicles.

According to the South African *Pedestrian and Bicycle Facility Guidelines* (draft 1.0) compiled by the National Department of Transport (2003), the following needs should be addressed in the planning, designing and construction of bicycle roads – class 1 and class 2 bicycle ways for exclusive use by cyclists:

- *"**Security**. A fundamental consideration is making persons feel secure when using the bicycle roads. The bicycle roads should not be located through areas that are secluded or deserted, and there should not be hiding places for criminals and vandals.*
- ***Traffic safety**. Traffic safety is an important consideration, because of the vulnerability of cyclists.*
- ***Accessibility**. The facility should be as accessible as possible to all cyclists.*
- ***Convenience**. The bicycle roads should be convenient to use. Cyclists desire a fast, direct, continuous, convenient route of access to the chosen destination.*
- ***Comfort**. The bicycle roads should be comfortable to use. Gradients should not be too steep, while a pavement of adequate construction should be provided.*
- ***Environment**. Cyclists prefer environments that are attractive. Great care should be taken in providing an environment that encourages cycling as a mode of transport.*
- ***Economy**. Bicycle roads should be economic. The roads should be designed to achieve the maximum benefit from their cost."*

The relative weights potential cyclists give to each of the listed requirements can be estimated through the utilisation of either aggregate or disaggregate / discrete mathematical models (Parkin *et al.*, 2007).

Fig 2.9 shows how traffic volume and speed determine the type of bicycle facility to be employed. When the traffic volume is low and the speed does not reach more than 30 km/h, cyclists can share the road with motor traffic. In zones with higher volume and / or speed, a form of separation is required. For an intermediate zone of volume and speed, a bicycle lane – the first level of separation - is sufficient to keep cyclists safe. Segregated facilities are necessary when the traffic volume and speed exceed 600 veh/h and 65 km/h, respectively.

A type of bicycle infrastructure not yet mentioned is the *bicycle box*, also known as advanced stop line, bicycle storage box, and heard start area. It has been employed in urban areas in Australia since the 1990s; there has, however, been little marketing of the related rules. The boxes are installed at some intersections with the objective to create a separate space for cyclists to wait during the red light phase; cyclists can enter the intersection first and gain their balance and momentum ahead of moving

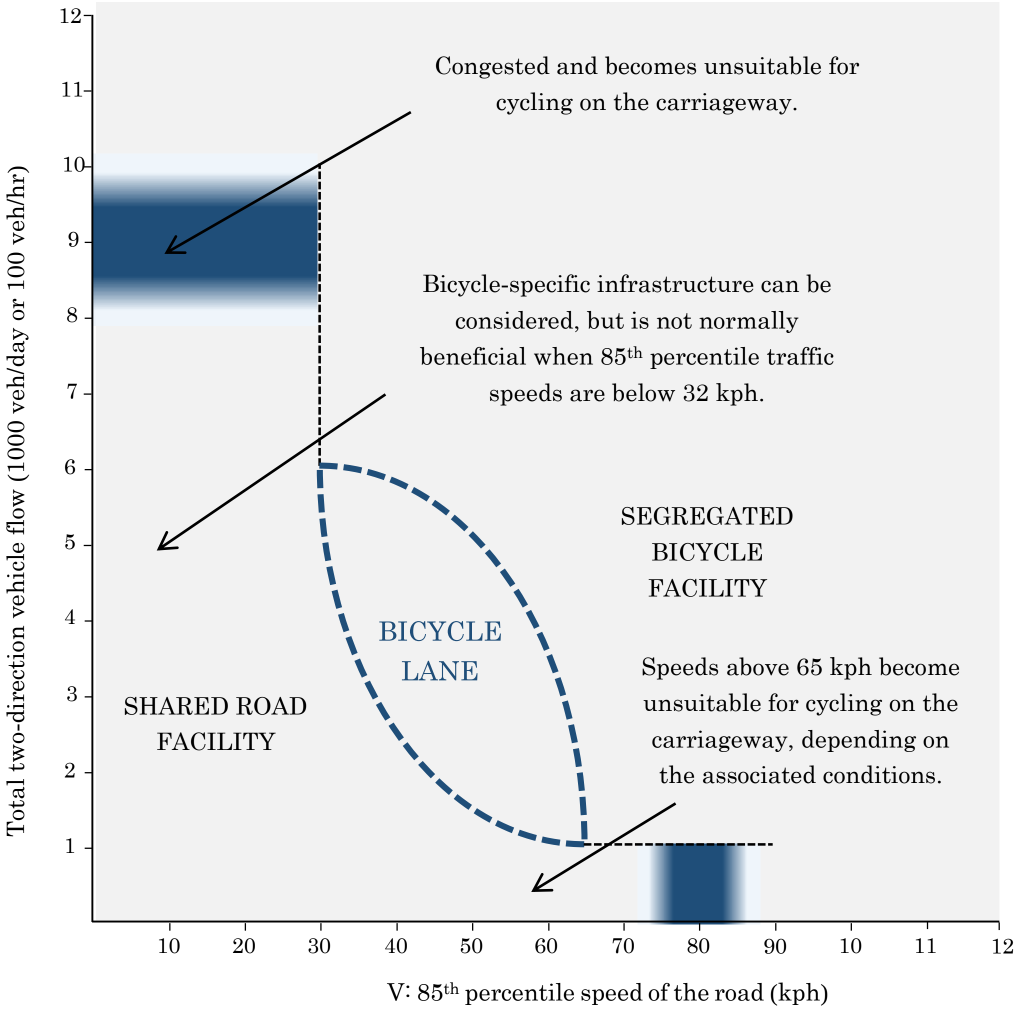


Figure 2.9: Determining the type of bicycle facility from traffic volume versus speed. Adapted from Transport Scotland (2011).

vehicles. This positioning increases cyclists' visibility and driver awareness. (Johnson *et al.*, 2014)

The PRESTO Cycling Policy Guide General Framework suggests a sequence of cycling development efforts across the three cycling stages (introduced in ***Section 2.4.1.2)***, with greater efforts on infrastructure suggested in the starter and champion stages (see ***Figure 2.10)***. More efforts on promotion are suggested for the climber stage.

2.4.2.5 REQUIRED RESOURCES

Whilst automated schemes eliminate the need for staff at all docking stations, (depending on the size of the scheme) significant human resources are still required for the efficient operation of the scheme. According to Transport Canada (2009), staff is required for the following general functions:

- **Fieldwork**: redistribution of bicycles, station maintenance and minor bicycle repairs.
- **Workshop**: major bicycle repairs.
- **Warehouse**: storage of spare parts, spare bicycles, and other equipment.
- **Call centre**: subscription management and customer assistance.

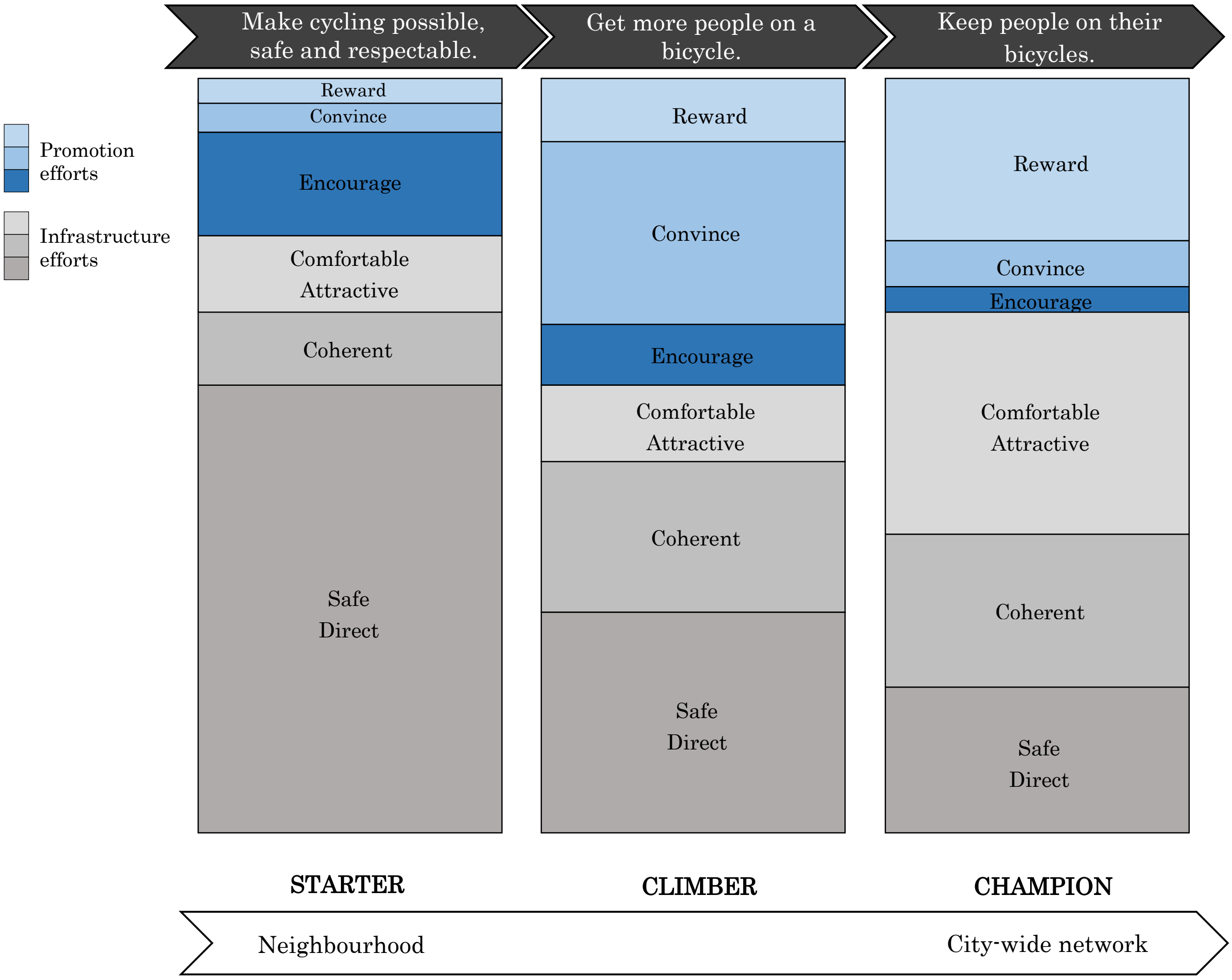


Figure 2.10: Sequence of cycling strategy efforts. Adapted from PRESTO Cycling Policy Guide General Framework (2010).

In addition to the bicycles and docking stations, other capital resources are required to maintain an adequate level of service of the scheme. These are:

- A **fleet of motor vehicles** for bicycle redistribution, station maintenance and minor bicycle repairs.
- **Warehouse facilities** for major bicycle repair, storage of spare parts and bicycles, and (in colder locations) for storage of the bicycle fleet and other equipment when the scheme shuts down for the winter months.
- **IT equipment** for monitoring the status of the stations, and the locations and status of bicycles.
- A **logistics centre** for coordinating redistribution, maintenance, and repair operations, as well as for customer service.

(Transport Canada, 2009)

2.5 MARKETING BICYCLE-SHARING SCHEMES

TDM was introduced in ***Section 1.2.1.4***, where it was said to only be a measure of congestion relief when alternatives are available. In many cities where bicycle-sharing became an option, TDM strategies were employed to promote the scheme and attract users. TDM strategies are divided into two broad types – structural (comprising physical changes, financial-economic stimulation and legal regulations) and psychological (comprising provision of information and education). Structural activities aim at changing the context of decision-making; psychological strategies aim at providing and / or increasing the knowledge people have of transportation alternatives and also increasing the awareness about the impact of decisions that may affect perceptions, beliefs, attitudes and values (Adjei & Behrens, 2012). The psychological TDM strategies can be seen as a form of marketing. To compete with other modes of travel and attract new users, various types of marketing must be performed for the bicycle-sharing scheme, especially when it is first launched.

With an objective to change the travel behaviour of individuals (in this case a mode shift from the private motor vehicle to the bicycle), it is essential to understand what causes individuals to change and accept alternative patterns of behaviour, so that the most appropriate TDM strategies can be employed. In the subsequent subsections, travel behaviour change theories are introduced, after which the different marketing strategies are described, and finally marketing activities related to the promotion of bicycle-sharing as suggested by others are presented.

2.5.1 TRAVEL-BEHAVIOUR-CHANGE THEORIES

The behavioural theories that have been developed are an attempt at explaining what stimulates consumers to make choices, how they are made and when change occurs (see ***Table 2.11*** to ***2.14)***. These theories are not necessarily contradictory, and may not be mutually exclusive. The theories approach behaviour as a function of either internal factors (values, attitudes, personal norms, etc.) or external factors (incentives, societal norms, institutional constraints, etc.), or both. In terms of changes in travel behaviour, the theory of planned behaviour is dominant in explaining behaviour. (Adjei & Behrens, 2012)

Table 2.11: Theories explaining how behavioural changes are made. Adapted from Adjei and Behrens (2012).

HOW ARE BEHAVIOURAL CHOICES MADE?
1. Rational choice theory (RCT) / utility maximisation theory
Consumers aspire to maximise their personal advantage (utility) by evaluating the costs and benefits of the alternatives that are available.
2. Prospect theory (PT)
This theory criticises utility theories for being useless when making decisions for which the outcome is uncertain. The theory proposes that people attempt to sidestep outcomes that provide uncertainty during the decision process. They do this by weighting alternatives with greater certainty of outcome higher than others.
3. Habit formation theory
An individual engages in rational deliberation to find a preference among a set of alternatives when presented with a choice decision for the first time. If a positive outcome results from the enactment of the preference-based choice, this set of steps (i.e. from deliberation, to choice, to experience of the positive outcome) is remembered; the individual can retrieve the memory in the future when confronted with the same decision-situation. Under the same conditions, the same choice is therefore repeated, forming a habit. Strong habits cannot be easily altered by small changes in state of affairs; the provision of information about alternatives is not effective in this case.

Table 2.12: Theories explaining the factors that affect choice-making. Adapted from Adjei and Behrens (2012).

WHAT FACTORS AFFECT CHOICE-MAKING?
1. Theories of reasoned action (TRA) and planned behaviour (TPB)
The TRA was developed to explain and predict volitional behaviours by the strength of **intention** (intention is thus the immediate determinant of action), but this cannot be done, since not all factors on which behaviours depend are always under the control of the person (e.g. time, money, skills and cooperation of others). As an extension to this theory, the theory of planned behaviour (TPB) was introduced to predict non-volitional behaviour. It argues that intentions can only predict a person's attempt to perform behaviour and not necessarily the actual performance of the behaviour. Intentions are determined by attitudes towards behaviour (a function of behavioural beliefs) and subjective norms (a function of normative beliefs)0.
2. Theory of interpersonal behaviour
The theory proposes habit, intention and facilitation conditions as the three determinants of behaviour, in order of importance. The stronger the habit, the less the effect of intentions on behaviour, and *vice versa*. Intentions are determined by attitude, social norms (subjective norms in TRA and TPB) and perceived behavioural control (not considered in TRA and TPB). Attitude is preceded by belief and evaluation of outcome (denoting the deliberative nature of humans), while social factors are determined by norms, roles and self-concept denoting the extent to which respected individuals and society affect behaviour). Perceived behavioural control represents the extent to which a person believes it is easy or difficult to perform an act.
3. Norm activation theory
The theory was posited to explain altruistic behaviour, and proposes personal norms as the determinant for pro-social behaviour. Personal norms are formed through an adaptation of societal norms, and these personal norms are said to be activated only when the person acknowledges the consequences of his or her behaviours, and takes responsibility for them. Four stages were developed through which normative decisions are made: (i) **attention** - the need for awareness to act, which should be uniform with one's personal norms, (ii) **motivation** for behavioural change, (iii) **evaluation** of the costs and benefits of enacting the various alternatives, and (iv) **denial** when no clear decisions are made. The process is repeated until a choice is made.

Table 2.13: Theories explaining when behavioural changes occur. Adapted from Adjei and Behrens (2012).

WHEN DOES BEHAVIOURAL CHANGE OCCUR?
1. Cognitive dissonance theory
A person will try to attain consonance (avoid dissonance) between two cognitions (i.e. thoughts, attitudes, beliefs or states of awareness of behaviour) if they are inconsistent or in conflict with each other. In efforts to achieve consonance and harmony, one of the two cognitions would need to be changed or rejected.
2. Stages of change model
The theory postulates six stages through which behavioural changes occur: **pre-contemplation, contemplation, preparation, action, maintenance and termination**. At the pre-contemplation stage, decision-makers have no intention of changing behaviour, since they are not aware of the consequences associated with their behaviour, or are in denial about it. Through the provision of information and social pressures, decision-makers may become aware of these consequences. Decision-makers then start pondering behavioural changes by considering the costs and benefits of various alternatives. After the decision-makers become aware of these costs and benefits, they prepare for behavioural change by formulating action plans. At the preparation stage, some behavioural changes may already be made. The action plan for behavioural change is then carried out. The maintenance stage, which follows, may be considered very important in the design of behavioural interventions, especially when dealing with habitual behaviours. Here, the decision-maker tries to avoid relapse to behaviour of the past. Maintaining the context within which the behavioural change occurred is hence important for the new behaviour to form into a habit. This new behaviour then changes personal norms, and the temptation to relapse to past behaviour becomes minimal.

Table 2.14: Theories explaining how decision-makers respond to behaviour-change interventions. Adapted from Adjei and Behrens (2012).

HOW DO DECISION-MAKERS RESPOND TO BEHAVIOUR CHANGE INTERVENTIONS?
1. Self-perception theory (SPT)
An individual discovers or alters his / her attitudes, emotions, and other internal states by observing his / her own behaviour and experience. In contrast to the CDT, and most other behavioural theories, this theory is nonsensical, since behaviour is presumed to precede attitude. An individual's attitude towards a particular behaviour may alter after performing the specific behaviour.
2. Goal setting theory (GST)
Human behaviour is motivated by conscious purpose, which is sequentially controlled by the decision-maker's goals. The theory focuses on the performance of behaviour - i.e. why some people perform better than others when given the same information and ability. The main explanation for this is that people have different goals. Two main factors in setting goals - **content** and **intensity** - are seen to determine the level of performance. Whilst content refers to how specific and difficult the set goal is, intensity determines the clarity and commitment of the person to attaining the goal. For better performance in behavioural change, the goal should be specific, challenging, achievable and appropriate.

2.5.2 MARKETING STRATEGIES

A marketing strategy coordinates several marketing activities into a plan that has a defined goal with regard to the provision of a service and the attraction of users. In his book *Urban Transit – Operations, Planning and Economics*, Vuchic (2005) defines four marketing strategies, namely undifferentiated marketing, differentiated marketing, concentrated marketing and individualised marketing. These are explained below. All could be applied to promote a specific bicycle-sharing scheme.

2.5.2.1 UNDIFFERENTIATED MARKETING

Undifferentiated marketing is a strategy in which a transportation mode or service (in this case bicycle-sharing) is provided and promoted in such a manner that it appeals to the public at large, i.e. the entire population of a defined service area with a single service / promotion package. Undifferentiated marketing is usually the simplest marketing strategy to implement, but is only effective when the individuals of the population have reasonably uniform characteristics.

2.5.2.2 DIFFERENTIATED MARKETING

In differentiated marketing, the population is divided into segments based on their varying needs, e.g. scholars, students and general commuters. The transportation mode or service (e.g. bicycle-sharing) is then uniquely promoted to each individual segment, so that in due course it appeals to everyone. Differentiated marketing is typically more costly than undifferentiated marketing, because it requires diversity and specialisation (Vuchic, 2005). The higher investment cost is, however, often compensated for by increased support on part of the users and hence higher revenues.

2.5.2.3 CONCENTRATED MARKETING

Concentrated marketing is a strategy that has its goal either the promotion of a single component of a transportation service or the attraction of selected segments of the population, e.g. only students.

2.5.2.4 INDIVIDUALISED MARKETING

This strategy aims to permanently change travel habits and increase the regular usage of a specific transportation mode or service, e.g. bicycle sharing. Several groups of potential service users are selected and personally contacted, with the intention to make them think about, and possibly change, their current travel behaviour. The selected groups are thoroughly informed about the service, since it is recognised that many people do not use a service, because they are not familiar with it and / or have no experience in using it, or no motivation to do so. A free service pass, of, for example, a month, is given to these users, which generally increases the use of the service significantly. The experience gained from the first groups is used to apply the same concept of organising such an individual approach to inform and motivate potential users to use the service to many more individuals. The increased revenue attained from one round can be used to fund marketing for the next one. The individualised marketing strategy obviously involves initial effort and labour-intensive work with individuals, but it does ultimately result in permanent changes to travel behaviour for many of the individuals and greatly increases usage of the service.

2.5.3 MARKETING ACTIVITIES

In literature, various marketing programmes are described that were, and still are, used to promote specific bicycle-sharing schemes and bicycle-sharing in general; suggestions are also made. These programmes can be attributed to two marketing activities: information distribution and advertising.

It is suggested that the launch of a bicycle-sharing scheme is accompanied by a professional media campaign (IEE 2011). This includes developing a unique and highly recognisable brand, as well as a social identity, for the bicycle sharing scheme (Transport Canada, 2009; Dhingra & Kodukula, 2010). The information campaigns on bicycle-sharing should attempt to improve the image of cycling, and communicate all the benefits the mode is able to afford to its users and society as a whole. Transport Canada (2009) adds to this that emphasis should be placed on the fact that bicycles DO belong on the roads. Dhingra and Kodukula (2010) say that a bicycle-sharing scheme should be promoted frequently and widely amongst different channels, with public officials and other celebrities partaking in this promotion. Certain population groups could be targeted individually, e.g. information on a town's bicycle-sharing scheme could be distributed to students during orientation week (IEE, 2011). Büttner *et al* (2011) furthermore identify that bicycle-sharing schemes are particularly suitable as part of combined communication measures. A bicycle-sharing scheme could, for example, be advertised in combination with a *car-free weekend* project or a *cycling safety awareness* programme.

In addition to general marketing, Transport Canada (2009) and Dhingra and Kodukula (2012) suggest specific actions for driving membership sales. These include free or discounted trips in the first month/s, pre-sales of discounted long-term memberships before the launch of the scheme, and incentives for lifelong members, students, senior citizens, etc. similar to the *Vitality* rewards programme by *Discovery* (a South African medical aid). Dhingra and Kodukula (2012) suggest that employers, cinemas and chain stores provide incentives to people who commute by bicycle.

3 RESEARCH DESIGN

3.1 INTRODUCTION

This chapter provides a framework of the overall approach that was taken to test the research statement of this research project: a bicycle-sharing scheme for school and university destined commuter traffic forms an integral part in achieving sustainable mobility in Stellenbosch, and is economically viable as a measure of congestion relief. The approach was a combination of common research designs that provided the necessary means to perform a CBA for a phased implementation. It comprised an extended literature review, survey-based research, evaluative research, a case study, and a simulation. The subsequent subsections discuss (in order) the application of these research designs in the research project, and how they came together to feed the CBA. The strengths and weaknesses of each design pertinent to this research project are also stated.

How the approach was ultimately implemented, and which tools and methodologies were applied to do so, is conversed step by step in ***Chapter 4***.

3.2 EXTENDED LITERATURE REVIEW

Application. The extended literature review provided dispensable data on common and best practice that is typically applied elsewhere. Whilst all schemes are context-sensitive, this information was essential for conceptually designing an appropriate and effective bicycle-sharing scheme for Stellenbosch. The extended literature review was also valuable as a comparison when the results of the CBA for bicycle-sharing in Stellenbosch were evaluated. The literature review was presented in ***Chapter 2***, and will not be elaborated on again here.

Strengths. Literature on bicycle-sharing is readily available, and the electronic resources of the SU made this information easily accessible when apt keywords were searched for. The extended literature review enabled the researcher to compare her findings to those obtained in other cities / towns and for different focus groups / populations, and to verify the magnitude of her findings. It is believed, that the extended literature review also added worth to the research, because by no means would all the studies referred to in this research project have been carried out to obtain the data these analyses provide, and hence valuable information would have been omitted.

Weaknesses. The review was limited to the availability of literature; data on certain subfields was naturally easier to find than data related to other subfields (e.g. a comprehensive breakdown of the costs of bicycle-sharing schemes was difficult to find, whilst the history of bicycle-sharing was repeated frequently in the literature).

3.3 SURVEY-BASED RESEARCH

3.3.1 OVERVIEW

Application. The analysis of the random results of two electronic surveys followed the extended literature review of bicycle-sharing. The survey-based research was employed to establish the number of users per road-user group (scholars, SU students and staff) that could potentially be persuaded to shift towards public bicycles, an alternative mode of transportation. From the number of potential users, the demand for bicycle-sharing could be estimated, which was essential for determining the size of the system, as well as the distribution of docking stations and the Drop-and-Go / Park-and-Ride. The survey made use of the opportunity to ask participants to provide feedback on their perception of the extent of AM-peak congestion in Stellenbosch. This gave an indication on how the public feels about the need for congestion relief and alternative modes of transportation.

The procedures relating to the distribution of the surveys is described in ***Section 4.7.1.1*** for the schools, and ***Section 4.7.1.4*** for the SU students and staff.

Strengths. The online survey method made data collection cost-effective, convenient and relatively easy to administer. The electronic questionnaires also allowed for certain 'logic' to be built into the questions. In this way, more questions could be included, as no time was wasted on the part of the respondents by reading unrelated questions. The responses were easily exported to an electronic spreadsheet programme (Microsoft Excel), which allowed filtering, statistical techniques and mathematical operations to be applied to the data effortlessly. Surveys in general, furthermore, have a high representativeness in that they are able to collect data from a large population. This often makes it easier to find statistically significant results than with other data collection methods, such as personal interviews, for example.

Weaknesses. Due to the anonymity of the surveys, the surveyor could not go back and ask a respondent to elaborate on his / her answer, or substantiate it. In general, but highly unlikely for the surveys of this research project, there is no guarantee for the reliability of the collected data, as respondents may not have felt encouraged to provide accurate, honest answers, and may not have felt comfortable providing answers that present themselves in a bad light. Data errors due to question non-responses may also have arisen. The number of respondents who chose to respond to a specific survey question may be different from those who chose not to respond, thus creating bias. For example, the participants that are highly frustrated by the traffic congestion, were perhaps more likely to respond to the questionnaire (in the hope of an improvement) than those that are not as affected and not as frustrated. The answer options to certain questions could have led to data errors too, because answer options may have been interpreted differently by the respondents who gave their own meaning to these options. The surveys that were used by the researcher from the very beginning, as well as the method of administering it, could not be changed all throughout the process of data gathering. Although this inflexibility in design could be viewed as a weakness of the survey method, it could also be a strength considering the fact that preciseness and fairness could both be exercised in the studies.

3.3.2 SURVEY CONTENT

3.3.2.1 SCHOOL SURVEY

The questionnaire on travel characteristics that was distributed to all the parents (no bias) of seven schools in Stellenbosch was introduced in ***Section 1.1.3.2***. It formed part of an undergraduate final-year project that studied the characteristics of school-generated traffic in Stellenbosch. The author proposed this research topic, so that a basis for her eventual master's research could be formed. The author worked closely with the final-year student in creating the survey and analysing the results (of all the schools). Although the survey was distributed ahead of the commencement of this research project, questions indirectly relating to the employment of bicycle-sharing in Stellenbosch were included in the interim. As mentioned, the eventual data analysis performed in this research project, was more specific and only performed for Bloemhof Girls' High, Paul Roos Gymnasium and Rhenish Girls' High.

Figure 3.1 illustrates the flow of the questionnaire and its logic. Only the questions applicable to this research project are included in this flow chart. A copy of the full questionnaire is included in ***Appendix C.1***.

The survey began with questions on household demographics. These questions collected the following information from the respondents:

- Trip origin, i.e. in which suburb the respondent lives
- The number of school-going children per household
- Whether all the children in the household are driven to school in the same private motor vehicle
  (This avoided repeating questions with regard to mode choice per child.)

The second section of the questionnaire asked the parents for child-specific information on each child in the household. The information encompassed the following:

- Whether each child is a boarder or not
- Which school each child attends
- In which grade each child is
- Which mode of transport each child uses, if not the same motor vehicle for all children is used.
- The motive for the mode choice

(This compiled a mode-choice trend per school and determined to what extent each school contributes to the AM-peak congestion in Stellenbosch.)

The third section of the questionnaire enquired information relating to the trip:

- Whether the trip to school by private motor vehicle is a detour or *en route* to the end destination, e.g. work
- The distance travelled to school, and the time required to cover this distance
- At what time the school trip is generated in the morning during the summer and winter months on a typical day
- When the mode of transportation is cycling, whether a helmet is worn
- When the mode choice is not an active mode of transportation, what the barriers are preventing the use of such a mode

The fourth and final section of the questionnaire asked about the perception of the current traffic condition in close proximity to the schools, and the level of frustration developed as a result of this congestion.

3.3.2.2 STELLENBOSCH UNIVERSITY SURVEY

The questionnaire on travel characteristics distributed to all the SU students and staff residing in the southern suburbs / towns of / to Stellenbosch was also introduced in ***Section 1.1.3.2***. The content of

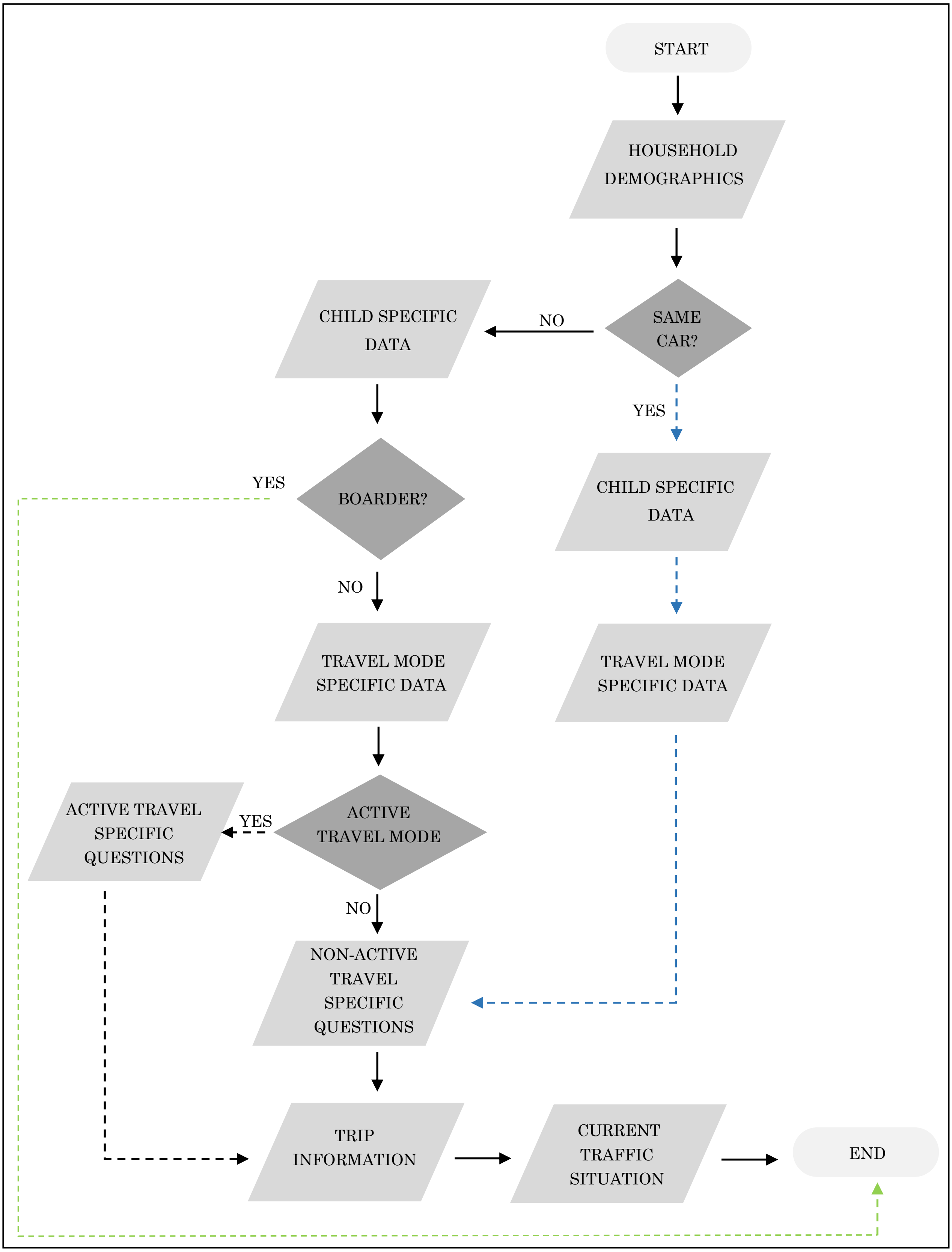


Figure 3.1: Flow chart and logic of the electronic questionnaire distributed to the parents of Stellenbosch scholars.

this survey was very similar to that of the school survey. ***Figure 3.2*** illustrates the flow of the questionnaire and its logic. A copy of the full questionnaire is included in ***Appendix C.2***.

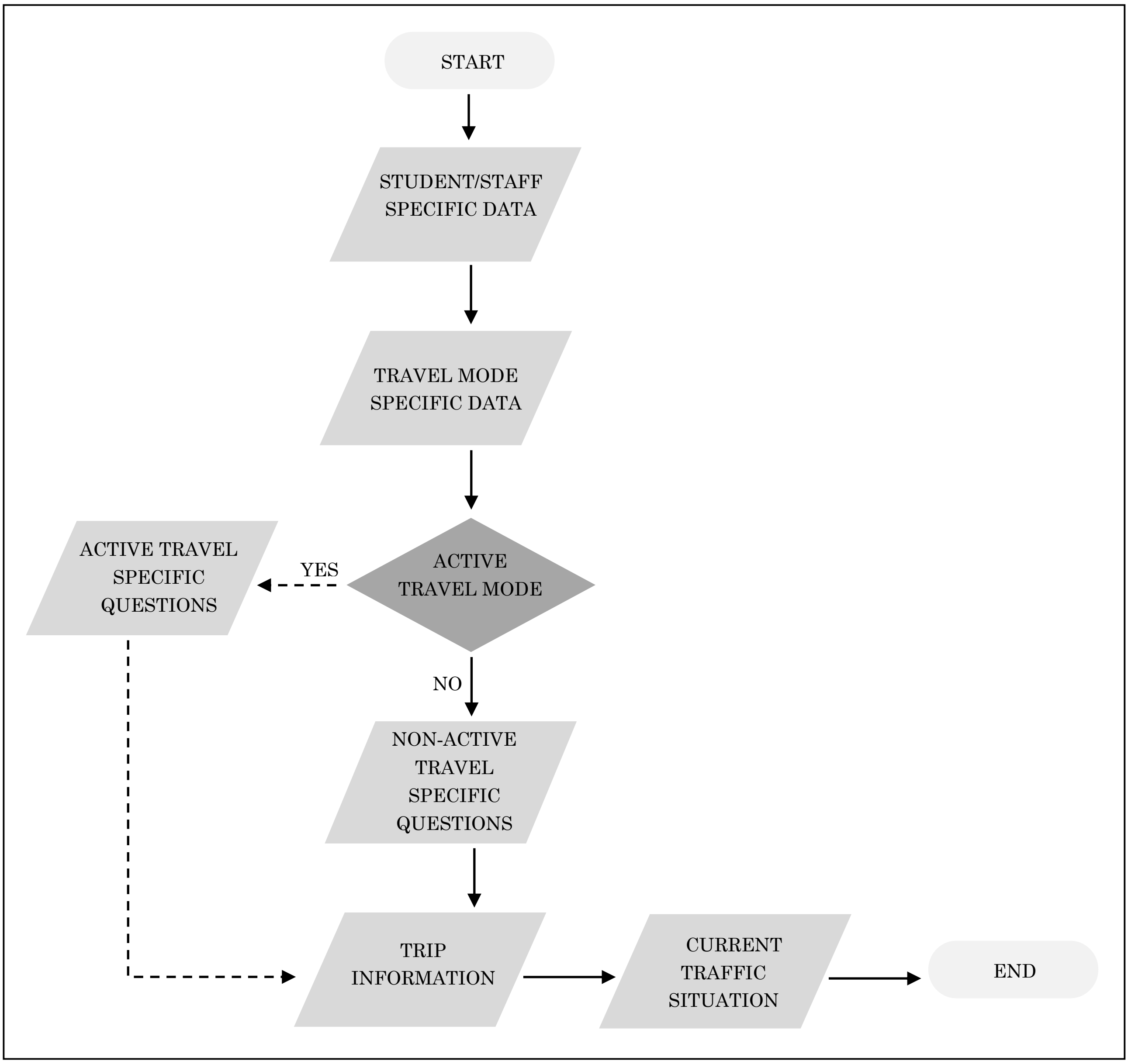


Figure 3.2: Flow chart and logic of the electronic questionnaire distributed to SU students and staff residing in the southern suburbs / towns of / to Stellenbosch.

The survey began with questions on demographics. These questions collected the following information from the respondents:

- Whether the respondent is a student or staff member
- Gender
- Field of work / study
- If the respondent is a student, whether he / she is an undergraduate or postgraduate student
- Whether the respondent studies / works full-time or part-time

The second section of the questionnaire asked the respondents for information relating to their mode choice. The information encompassed the following:

- Whether the respondent is part of a lift club / carpool
- If yes, how many other students / staff members are part of this lift club / carpool
- If the respondent is driven every morning, whether the SU campus is *en route* to the final destination of the driver

- Parking details
- Whether cyclists wear helmets

The third section of the questionnaire enquired information relating to the trip:

- At what time the respondent traverses the section of the R44 between the Stellenbosch Square shopping mall and Die Boord
- The distance travelled from home to the SU campus

The fourth section related to cycling and asked for the following information:

- The extent to which certain barriers prevent the respondent from cycling to the SU campus on a daily basis
- Assuming that *travelling distance is too far* is the only barrier preventing the respondent from cycling on a daily basis, what the maximum acceptable distance is that the respondent would be willing to cycle to the SU campus
- To which degree the respondent agrees or disagrees with the following statement: *"I support changes to cycling development and the provision of cycling facilities in Stellenbosch."*

The fourth and final section of the questionnaire asked about the perception of the current traffic condition in the AM peak hour within 2 km of the SU campus, and the level of frustration felt towards this congestion.

3.4 EVALUATIVE RESEARCH

3.4.1 OVERVIEW

Application. Evaluative research formed the focal research design of this research project. The former designs were implemented for the sake of the conceptual design of the bicycle-sharing scheme, and its various scenarios, for which a CBA was undertaken in the end. The analysis was performed for:

1. scholars only;
2. scholars and SU students only; as well as
3. scholars and SU students plus staff.

The appraisals were predominately of a quantitative nature, eventually expressed in monetary terms, but also of a qualitative nature when a quantification was not possible. This combination of quantitative and qualitative research is known as mixed methods or methodological triangulation.

An evaluative research design was, moreover, applied when evaluating Stellenbosch's prevailing traffic condition and quantifying the project alternatives.

Strengths. On the whole, unlike an opinion, quantitative studies produce sound answers to research project statements (if executed correctly). A strength of CBAs is their simplicity; they are easy to understand, especially when expressed in monetary terms, and hence may have high credibility with authorities. Quantitative studies are also replicable, as they comprise guiding principles that other researchers can copy. This means that there is consistency in the methodology.

Weaknesses. The simplicity of CBAs can result in data errors and complications. If the assumptions and estimations are inaccurate, a project could be deemed viable, when in actual fact it is not. The opposite could also present itself, however; a project is not implemented since the costs were overestimated and / or benefits underestimated. A disadvantage of CBAs is also the common unit that needs to be used. It is a challenge to quantify qualitative benefits, and as a result, an apples-to-apples comparison is not always possible. Furthermore, if accuracy with regards to the costs and benefits is not closely monitored, some benefits can easily be counted double when they are not independent of each other.

3.4.2 CASE STUDY

Application. This research project aimed to provide a first-order presentation of the benefits bicycle-sharing is able to provide to Stellenbosch and its residents. The scope of the research project, however, did not allow for such an analysis of the benefits to be performed for the entire town. A case study was hence used as part of the evaluative research to test the hypothesis of the research project for the vehicles entering the town via the R44 corridor from the Somerset West direction. A clear description of this case study and study area was given in the introductory chapter of this study in ***Section 1.3.3***. The acquired benefits of the case study can either be extrapolated where possible, or the methodology can be applied to other parts of Stellenbosch.

Strengths. Case studies are useful when detailed knowledge of an alternative is required, but time is a limiting factor, and also when authorities, for example, are dubious about the success of a project and wish to first 'test the waters' before wasting time on a full analysis (i.e. case studies provide insight for further research). Both of these scenarios applied to this research project.

Weaknesses. In general, the extrapolation and generalisation of results to a wider population are often not scientifically accurate, since the researcher can never be certain whether the case that is investigated is representative of the whole population. One can also never predict for sure what will happen in the future, and what unforeseen events will skew such an extrapolation.

3.4.2.1 COSTS

The conceptual design of the bicycle-sharing scheme for Stellenbosch was as comprehensive as required to evaluate the cost of constructing, launching, operating and maintaining such a scheme for the case study. A breakdown of the costs of the bicycle-sharing scheme for Stellenbosch is shown in ***Figure 3.3***. The costs include construction costs, equipment costs, launch and implementation costs, as well as operating and maintenance costs. Potential revenue can be subtracted from these costs.

3.4.2.2 BENEFITS

As mentioned, the benefits were evaluated for the case study only, but some of these benefits allowed for an approximate (and mostly qualitative) extrapolation to the wider Stellenbosch. A breakdown of the evaluated benefits of bicycle-sharing is given in ***Figure 3.4***. These benefits are either from the point of view of the authorities, society or the bicycle-share users. The qualitative benefits are marked with an asterisk (*) and were described, but not included in the economic evaluation procedure.

Irrelevant of the investor and owner of the bicycle-sharing scheme, the scheme could provide indirect benefits to society as well as the authorities. The benefits evaluated for the remaining road users - those not shifting to the public bicycle - were a decrease in congestion / improvement in LOS, reduction in external costs, public health benefits, improved safety and security for current NMT users, publicity and improved liveability. The likely decrease in congestion is a mobility benefit, and could result in increased average travel speed, reduced average travel times, reduced average time delays and

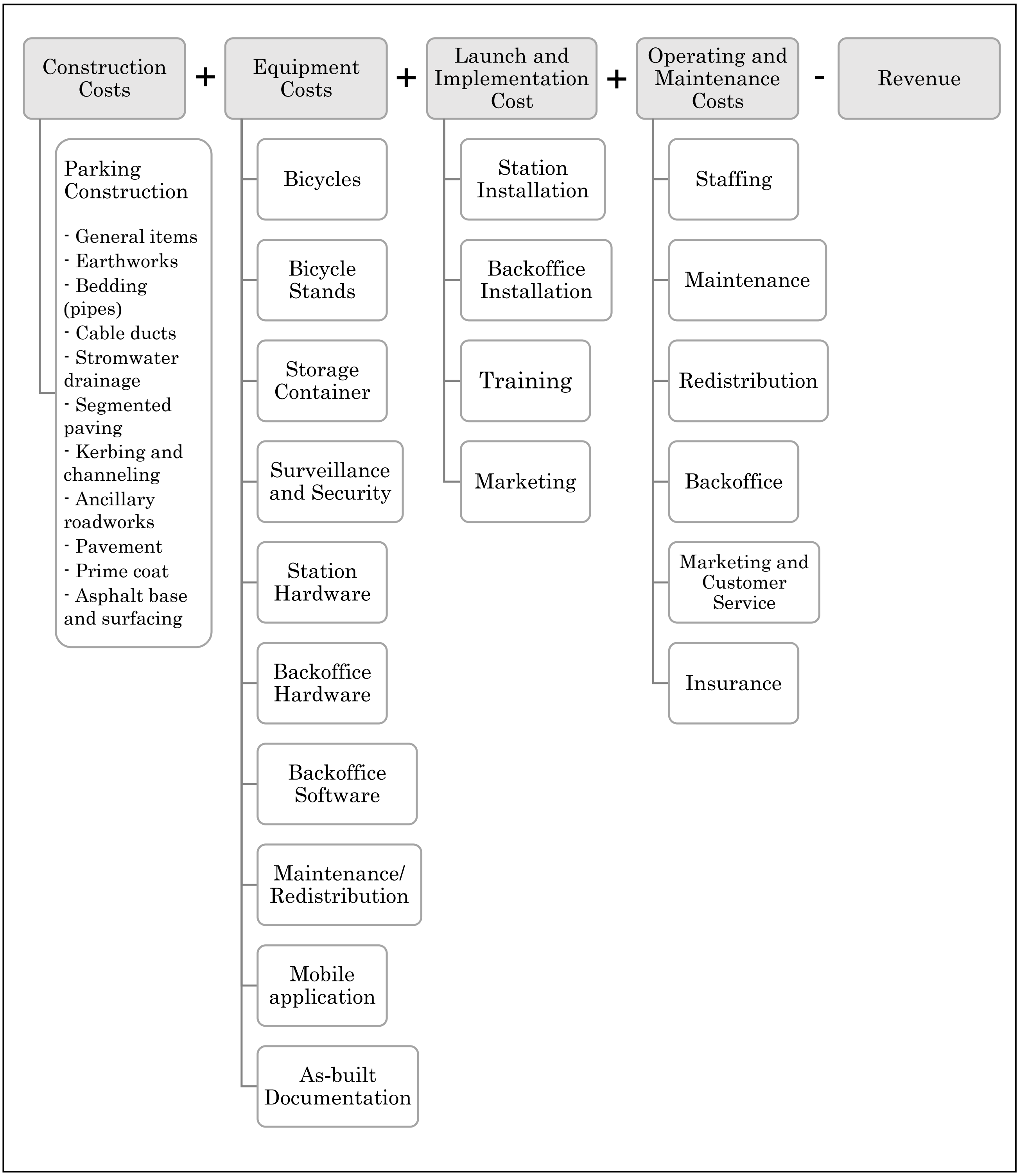


Figure 3.3: Diagrammatic breakdown of the costs of a bicycle-sharing scheme for Stellenbosch.

improved accessibility. These benefits were expressed in terms of their respective units, but were represented as part of a reduction in the vehicle operating cost per road user in the economic evaluation. The appraised environmental benefits comprise a reduction in CO_2 emissions. Other probable savings in costs are those related to a reduction in accident costs from reduced accidents, since the traffic volumes on the network are lower. The evaluated public health benefits are reduced general stress levels among the residents and commuters, a decrease in morbidity, and a reduction in mean annual mortality. An increase in NMT users could also improve safety and security for the

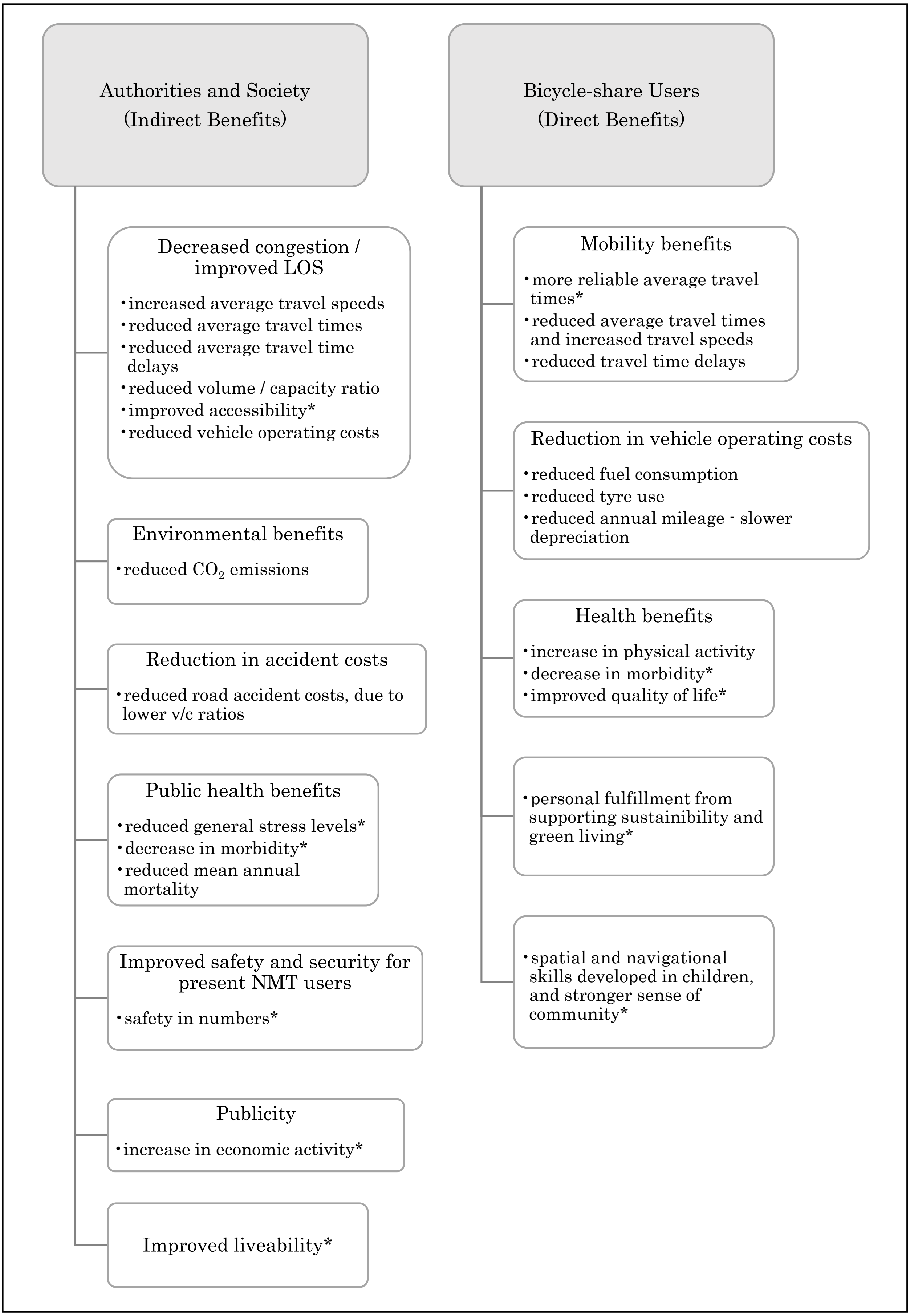


Figure 3.4: A breakdown of the benefits of the bicycle-sharing scheme for Stellenbosch.

present NMT users. With its smart mobility, Stellenbosch could receive a lot of publicity, and very likely an increase in economic activity as a result. All in all, the benefits listed could improve liveability in Stellenbosch.

The likely direct benefits to the bicycle-share users who were identified in this research project are mobility benefits, a reduction in transportation costs and health benefits (only qualitative). The mobility benefits are reduced and more reliable average travel times, increased travel speeds and reduced travel time delay. These benefits were expressed in units of time and distance before they were converted to a monetary unit for the CBA. The reduction in transportation costs is represented by a reduced fuel consumption, reduced tyre use and a reduced annual vehicle mileage per bicycle-share user. Health benefits comprise an increase in physical activity, a decrease in morbidity and an improved quality of life. Furthermore, a personal fulfilment from supporting sustainability and green living could be realised. And, in the case of the scholars, spatial and navigational skills could be developed, as well as a stronger sense of the community.

3.4.3 SIMULATION

Application. Traffic demand modelling and micro traffic simulations were used as part of the evaluative research to aid in determining, and eventually presenting, the mobility benefits the bicycle-sharing scheme is able to attain for the entire study area and also at particular intersections within this study area.

Strengths. Simulations have a potentially large theoretical significance, since they can explain, and specifically show, a lot about a particular phenomenon. When presenting the non-monetary impacts of a transportation implementation to stakeholders who are not from the field of transportation, greater success is often achieved with a visual simulation of the change and reduction in traffic flow, for example, than with a verbal feedback of the results comprising transportation jargon. The demand model that was created for this research project also reduced the number of hand calculations that needed to be done, which hence saved valuable time.

Weakness. No simulation is reality; it will always be a simplification of reality.

4 RESEARCH METHODOLOGY

4.1 INTRODUCTION

Chapter 3 described the overall approach that was taken to test the research statement. The research methodology builds on that chapter in that it discusses in sequential order how this approach was carried out. The chapter begins with a more detailed description of the study area as well as an overview of the research evaluation process, and then converses the method behind the evaluation of the prevailing conditions. Here, the *PTV Visum 15* traffic demand model is introduced. The project alternatives are defined next. The chapter continues with a description of the cost analysis, where the costs are described as shown in the breakdown in ***Figure 3.3***. This is followed by an explanation on how the benefits portrayed in ***Figure 3.4*** were assessed for different scenarios of the bicycle-sharing alternative, and what attempts were taken to extrapolate these benefits to represent overall benefits. Furthermore, the application of economic and financial analyses is discussed, and it is enlightened which shadow prices were applied where. Finally, the economic evaluation techniques are defined.

This chapter maps on to almost all succeeding chapters, where the results to the methodologies described here are revealed.

4.2 DESCRIPTION AND DEFINITION OF THE LINK / NETWORK

To ensure that the most effective evaluative research was applied to the study area, it was required to study the attributes and physical features of the network, i.e. assess the function of the links within the network, determine what types of land uses are served by the links, and identify the location and control types of the main intersections found within the network. The study area is divided into two parts:

1. the R44 corridor that runs in a northerly direction from the intersection with Annandale Rd to the intersection with Van Reede Rd in Stellenbosch, and
2. the area within the polygon enclosing *Krigeville*, as defined and already explained in ***Section 1.3.3***.

It is important to note that the corridor only refers to the inbound traffic into Stellenbosch.

The starting-point of the corridor was purposefully set so far back, because the locations of the Drop-and-Go zone and Park-and-Rides were not yet known at the time, and the author wanted to ensure that no key aspects of the R44 are overlooked when defining these locations. According to the TRH 26 - South African Road Classification and Access Management Manual, the corridor is a Class U2 (urban major arterial) dual carriageway. It covers a total distance of 6.4 km, and has a speed limit varying between 60 km/h and 100 km/h. The speed limit is 100 km/h for the first 2.6 km, 60 km/h for the last 300 m and 80 km/h for the rest of the route. Six signalised intersections are found along the route, including at the start and at the end (see ***Figure 4.1***). The route transports traffic from Somerset West, but the residential estate De Zalze, and the residential areas Jamestown and Paradyskloof, also generate many vehicle trips with destinations in Stellenbosch. In addition to these residential land uses, this feeder route, furthermore, serves the shopping centre Stellenbosch Square and the business park Technopark.

The segments of the R44 between Van Reede Rd and Dorp St provide access to and from the residential area, shopping centre and private hospital in Die Boord, and also access to and from Adam Tas Rd.

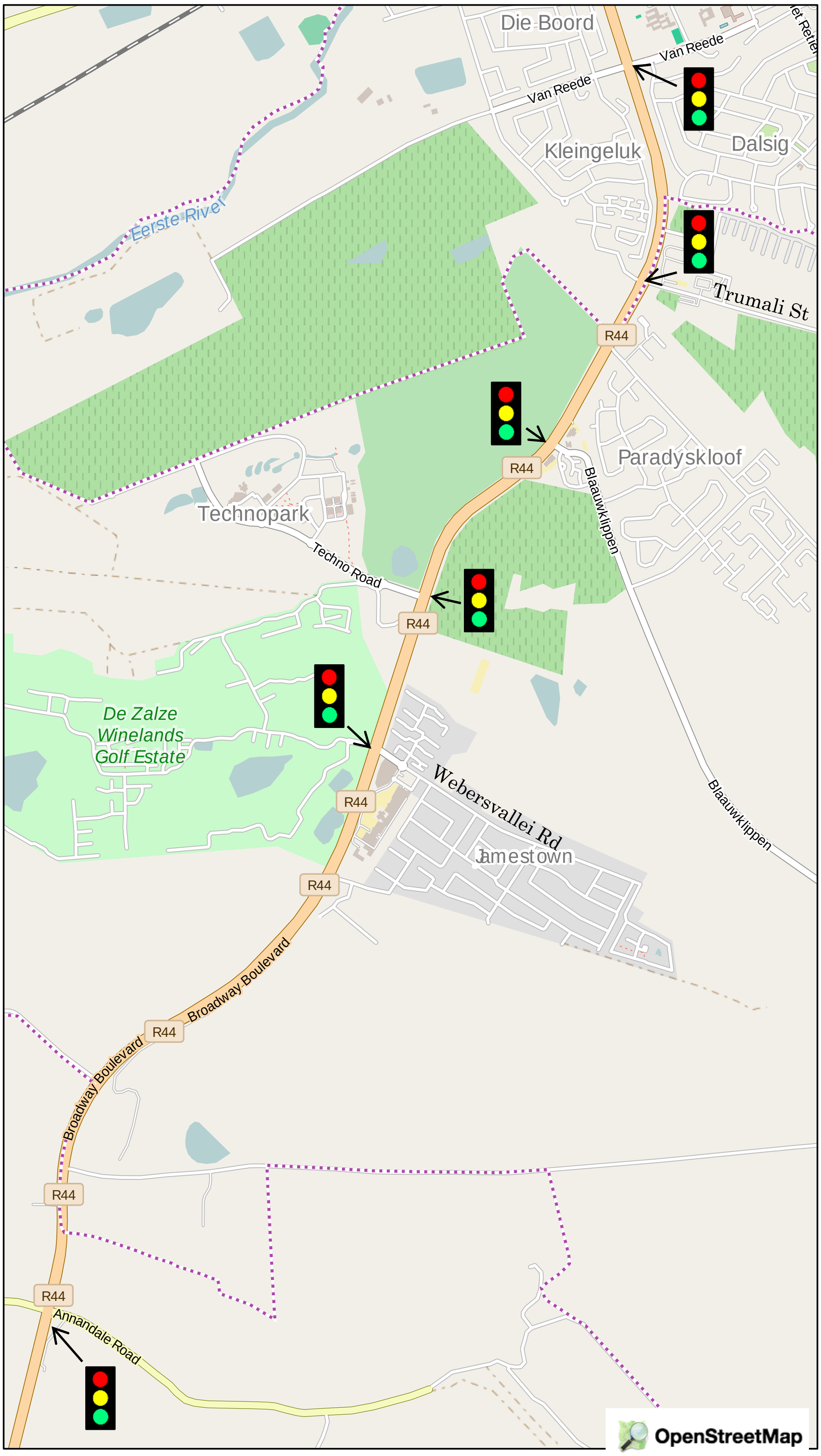


*Figure 4.1: The studied corridor of the research project, and the location of its signalised intersections. (Area 2 on map in **Appendix A.1**)*

Dorp St, Piet Retief St, Vrede Rd and Van Reede Rd (part of the polygon around Krigeville) are Class U4 urban collector streets with speed limits of 60 km/h. Van Reede Rd collects traffic from the residential neighbourhoods Brandwacht, Dalsig and Die Boord. Along Dorp St, the primary land use is commercial activities (e.g. coffee shops, restaurants, offices and shops). The fact that five schools are located in close proximity of each other in Krigeville was highlighted numerous times in ***Chapter 1***. Five major intersections are located along the perimeter of the polygon (see ***Figure 4.2*** and ***Table 4.1***); three of these intersections are controlled by signalisation and two by a roundabout.

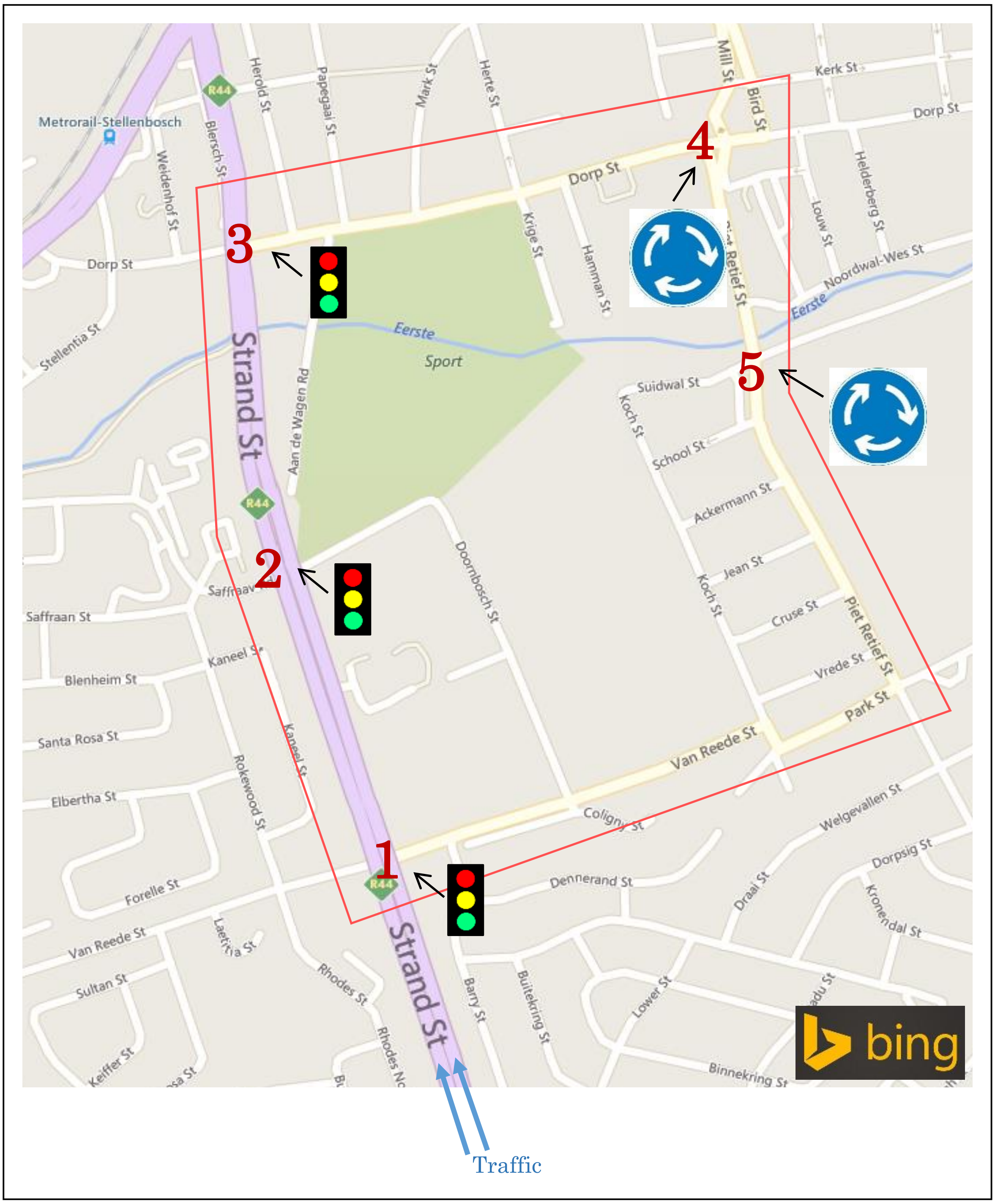


*Figure 4.2: Locations of the five major intersections around the study area in Krigeville. (Area 1 on map in **Appendix A.1.**)*

Table 4.1: Characteristics of the five major intersections around the study area in Krigeville.

Intersection no.	Intersecting streets	Control type
Intersection 1	R44 and Van Reede Rd	signalisation, semi-actuated (during AM)
Intersection 2	R44 and Saffraan Ave	signalisation, semi-actuated (during AM)
Intersection 3	R44 and Dorp St	signalisation, semi-actuated (during AM)
Intersection 4	Dorp St and Piet Retief St	roundabout
Intersection 5	Piet Retief St and Suidwal Rd	roundabout

4.3 OVERVIEW OF THE RESEARCH EVALUATION PROCESS

Figure 4.3 is a flow diagram showing the research evaluation process followed in this research project. It is an overview of what is to follow in this chapter, and includes the components that were introduced in ***Chapter 3***. The aim of the diagram is again to answer the 'why' questions. Why were the steps described in this chapter performed? What purpose do they serve in answering the research question? The diagram starts with the overall research question and then defines the methodologies that were applied to answer this question. Furthermore, the inputs that were required for these methodologies are described, as well as the tools that were employed to obtain these inputs. In some cases, the sources of input parameters are given in place of a toolkit. For the inputs that required several inputs of their own, a breakdown of their evaluation is given as for the overall research question. In the overview, it is also clearly shown when supplementary information and / or calculations were needed, and these are then described. The sections of this chapter elaborate on what is depicted in ***Figure 4.3***.

4.4 PREVAILING TRAFFIC / TRAVEL CONDITIONS AND AM PEAK HOUR

Since it is assumed that all modal shifts to the public bicycle will be made from the private motor vehicle, an investigation of the current motor vehicle travel conditions within the study area was needed as a point of reference for the research methodology. Mobility and environmental impacts were investigated as part of this evaluative research. Various tools and research instruments were employed to attain the results. These are **traffic volume counts**, the **TomTom Stats Portal**, the **PTV Visum 15 demand modelling software package** and the **Highway Capacity Manual (HCM) 2010**. It should be noted that the prevailing conditions are not the conditions against which the bicycle-sharing benefits are measured against, because the annual traffic growth in the study is not yet accounted for (see the null alternative in ***Section 4.5.1)***.

4.4.1 TRAFFIC VOLUME STUDY

Traffic volume counts are counts of traffic conducted to reflect on the number, movements, and classification of motor vehicles at a given point on a roadway facility during a specified time period. With the data, critical flow time periods and popular routes can be identified, the influence of heavy

THE QUESTION / REQUIRED OUTPUT	METHODOLOGY	INPUT	TOOL / SOURCE OF INFORMATION	SUPPLEMENTARY CALCULATIONS / INFORMATION
Is a theoretical bicycle-sharing scheme for commuter traffic in the town of Stellenbosch economically viable?	▫ **First year rate of return study area** ▫ **Net present value (NPV) technique for study area** ▫ **Benefit/cost ratio (BCR) for study area**	<u>**Economic factors**</u> ▫ **discount rate** ▫ **base / evaluation date** ▫ **service / facility lifespan**	The World Bank - real interest rate User-defined - with reference to 2015 *Cycling Plan for the Town of Stellenbosch* User-defined - after feedback from personal interviews about service life of equipment	<u>**Define project alternatives**</u> ▫ **Null alternative: do-nothing option** normal traffic growth at 3% per annum ▫ **Bicycle-sharing for commuter traffic from direction Somerset West** as described in *Section 1.3.3* ▫ **Geometric improvement to R44 / Van Reede intersection currently underway in phases** comparing benefits and costs to those of bicycle-sharing
	▫ **Sensitivity analysis**[1]	**▲ PROJECT BENEFITS**		
	▫ **Extrapolation to wider Stellenbosch** discussion after economic evaluation for study area is complete.	**● PROJECT COSTS**		
		■ REVENUE ASSESSMENT		
▲ PROJECT BENEFITS	▫ Sum of all project benefits in monetary terms	♦ For the bicycle-sharing alternative: **potential users and reduced trips**		<u>► Define analysis period for calculation of project benefits</u> ▫ User-defined as AM peak, because congestion is at its worst in AM
		α Savings in road user costs ▫ vehicle operating cost (VOC) savings ▫ travel time savings ▫ accident cost savings		
		β Health benefits		
		δ Reduced environmental emissions		
		ε Other qualitative benefits		
► AM peak hour	▫ Analysis of speed profiles and cumulative travel time graphs for R44 corridor (= entry into study area)	▫ Avg. travel speed for different 1-hour AM time periods ▫ Cumulative travel time for different 1-hour AM time periods	TomTom probe data	
♦ Number of potential bicycle-share users and reduced trips	▫ Subtractions from total number of trip makers and trips per road user group (school learners, SU students and SU staff)	▫ Total number of trips per road user group ▫ For all 3 road user groups: vehicle occupancy ▫ For all 3 road user groups: mode of transportation ▫ For all 3 road user groups that are car passengers: number of trips *en route* to the driver ▫ For school learners: number of boarders ▫ For school learners: test for primary school siblings ▫ For SU students and staff: time of travel ▫ For SU students and staff: route of travel	Electronic survey distributed to parents of school learners, SU students and SU staff	
α VOC savings*	▫ Applying given formula for 2014 VOC to AM peak hour	▫ Fleet composition ▫ Mean system speed in AM peak hour	Traffic volume count PTV Visum demand modelling package[3] and TomTom probe data	

		▫ Vehicle kilometres travelled in AM peak hour	PTV Visum demand modelling package	
		▫ Inflation rate for VOC from 2014 to 2015	Stats SA - consumer price index June 2015	
α Travel time savings*	▫ Product of the AM peak link volume and the AM peak link travel time, summed over all links ▫ Extrapolation to annual costs	▫ Vehicle hours of travel in AM peak hour	PTV Visum demand modelling package and TomTom probe data	
		▫ Vehicle occupancy	Electronic surveys distributed to parents of school learners, SU students and SU staff	
		▫ Potential users per road user group	From potential users calculation, *see above*	
		▫ Value of time (VOT) per road user group	*Average SU salaries, average per capita income and survey results.*	
α Accident cost savings	▫ Educated guess/estimate, since accident HSM prediction model proven not to be accurate for SA roads.	▫ Analysis of frequency and location of accidents per annum per accident type during AM and PM in study area	Western Cape Transport Data Integration Site	
		▫ Accident costs per accident type		
β Health benefits	▫ Qualitative assessment ▫ World Health Organisation - Health Economic Assessment Tool (HEAT) for cycling		Literature review	
		▫ Duration - average time cycled per person = (avg. trip distance/average cycling speed)		
		▫ Number of cyclists = potential users	From proportions of each road user group in the number of potential users	
		▫ Average age of the cyclists		
		▫ National mortality rate	World Health Organisation	
		▫ Value of a statistical life (VSL)	Prof. Krygsman, SU Dept. of Transport Economics	
		▫ Time period over which benefits are calculated = service life		
		▫ Discount rate	*See economic factors above*	
δ Reduced environmental emissions*	▫ Emission calculation from fuel consumption ▫ Extrapolation to annual environmental emissions	▫ Mean system speed	PTV Visum demand modelling package	
		▫ Density of petrol and diesel fuel	internet research	
ε Other qualitative benefits safety benefits to existing NMT users job creation and economic stimulus psychological benefits	▫ Comprehensive literature review			
● PROJECT COSTS	▫ Sum of all project costs for the service lifespan minus residual/salvage value	▫ Capital costs ▫ Implementation costs ▫ Operating and maintenance costs ▫ Residual / salvage value	Internet research, quote requests and personal interviews	~ For the bicycle-sharing alternative: **the design and operations of the scheme** need to be known to evaluate costs
~ Design and operations of the bicycle-sharing scheme	▫ Comprehensive literature review and applying what was learnt to the town of Stellenbosch	▫ *See Section 2.4* ▫ Additional input: size of the scheme		
■ REVENUE ASSESSMENT	▫ Sum of all potential revenues	▫ Potential advertising revenue	Local research on advertising revenue potential	
		▫ Potential membership and user fee revenue	Literature review Elwierda local school bus fees VOCs	

Figure 4.3: Overview of the research evaluation process.

vehicles or pedestrians on vehicular traffic flow can be determined, and traffic volume trends can be documented. The studies are completed either manually or automatically. This is dependent on the count period, which can range from 5 minutes to 1 year. Peak-hour information should always be used in manual counts. Traffic volume counts are generally performed on a typical weekday from Tuesday to Thursday, and avoid special events and adverse weather conditions. Manual counters have the advantage that specific information, such as vehicle occupancy, pedestrians, turning movements and vehicle classifications can be obtained efficiently. This is not the case for all automatic counters. Automatic counts are normally used to gather data so that vehicle hourly patterns, daily or seasonal variations and growth trends, or annual traffic estimates can be established. Recent technological advancements in detection devices nowadays make it possible, however, to also classify vehicle types and determine average travel speeds. This is accomplished through artificial intelligence and image processing algorithms. Within manual counting, the three most common types of equipment are tally sheets, mechanical count boards and electronic count boards. For automatic counts, either portable or permanent counters are used. Video recording is also an automatic counting method, with digital clocks in the video image that help note time intervals.

The traffic volume counts referred to in ***Section 1.1.3.3*** as part of the status quo are from 2013, and hence new counts had to be conducted. The 2013 counts from the municipality also do not include all the intersections of the study area. These counted trips were the fundamental input to the Visum demand model, described in ***Section 4.5.1.3***. The volume counts were also used to find the AM peak hour of the study area, which was to serve as the analysis period for all calculations. It is generally during the peak period that operating conditions are the worst, vehicle operating costs the highest, and therefore, potential cost savings the greatest. Due to limited resources (equipment and human resources), new traffic volume counts at all of the intersections in the study area could unfortunately not be performed on the same day. On Thursday, 13 August 2015 counts comprising video recordings were conducted between 06:45 and 08:15 at the five major intersections shown in ***Figure 4.2*** and listed in ***Table 4.1***, as well as at the R44 / Trumali St major intersection. For all the minor intersections located between these intersections, video-recorded traffic volume counts were performed between 18 August and 2 September 2015 on either a Tuesday, Wednesday or Thursday. Volumes were recorded per 15-min time interval at all of the intersections. At the southern approach of the R44 / Van Reede intersection, heavy vehicles (defined as goods vehicles and buses) were counted separate from light motor vehicles (incl. minibus taxis), after which it was clear that vehicle classification could be ignored in this research project. The turn volumes for each movement at the minor intersections were calculated as proportions of the approach volumes, and these proportions were then multiplied by the produced approach volumes observed for the major intersections, i.e. the traffic volumes observed for all the intersections in the study area are based on the volumes counted on 13 August 2015. In the case of succeeding major intersections where the productions of a link at the first intersection did not equal the attractions of that same link at the second intersection, the produced and attracted volumes were balanced so that the volumes equalled the average of the two. The fact that the two volumes did not equal each other is not an error, but for modelling purposes it was required that the productions equal the attractions. The video counts allowed for more accurate results (i.e. less human error) in comparison to manual counts, because the recordings could be paused and rewound at any time, and viewed as often as necessary. This also put less pressure on the students undertaking the field study. The count locations are shown together with the results in ***Section 5.1***.

It can be rightly argued that a once-off manual count of movements at various intersections during the peak period does not provide a perfect basis either for an adequate analysis of the prevailing traffic conditions, or for determining future traffic growth; variations in traffic flows during a year, or even a week, are likely to occur. For the following reasons, the results of the traffic volume study performed for this research project appeared adequate, however, to use for the purposes they served:

1. traffic counts were only conducted on Tuesdays, Wednesdays or Thursdays (a typical day);
2. similar traffic conditions were observed for the counts conducted between 18 August and 2 September 2015; and
3. the CBA is only evaluated for weekdays (not weekends) that fall outside of the school and university holidays.

Since this research project is all about the incoming traffic from the R44 corridor, the morning peak hour was defined from the highest total of four consecutive 15min-volumes between 06:45 and 08:15 for the southern approach of the R44 / Van Reede intersection. Probe data was used to validate the peak hour (see ***Section 4.4.2)***. This peak hour, then became the analysis period for the research project, and traffic volumes for all the other intersections were only observed for this time period.

The peak hour factor (PHF) was also determined for the major intersections to measure the fluctuation of the traffic demand during the peak hour. The PHF is defined as the ratio of the total hourly volume of the peak hour to the peak flow rate within that hour, and was computed using ***Equation 4.1***. Typical peak hour factors for highways and freeways range between 0.80 and 0.95. Lower factors are characteristic of rural freeways or off-peak conditions. Higher factors (very close to 1) are typical of urban and suburban peak-hour conditions.

$$PHF = \frac{V}{4 \times V_{15}} \tag{4.1}$$

where
- V = hourly volume (veh/h), and
- V_{15} = volume during the peak 15 minutes of the peak hour (veh/15min)

4.4.2 PROBE DATA: TRAVEL TIME AND TRAVEL SPEED

The TomTom Stats Portal and probe data were introduced in ***Section 1.3.3***, where the definition of probe data was given. 2015 probe data was queried from the TomTom Traffic Stats Portal using the Custom Travel Times product to evaluate travel times and travel speeds for the roads included in the case study, and also to determine the morning peak hour. The peak hour was evaluated again to ensure that both methods (analysis of traffic volume counts and analysis of probe data) led to the same result.

The TomTom Traffic Stats Portal generates 4 output formats for each submitted dataset. These are:

1. a Keyhole-Markup-Language-Zipped (KMZ) file,
2. a XLS (Excel) file,
3. a shapefile, and
4. charts that can be viewed within the portal.

These outputs provide segment, speed and travel time information. The routes are divided into detailed road segments that range from approximately 1 m to not more than 2 km in length. The road segments are also split at every intersection or change in geometry and / or traffic conditions. For real-time traffic services, TomTom probe data sources include connected GPS devices and Global System for Mobile Communication (GSM) devices - both producing so-called Floating Car Data (FCD) - ; road sensors (usually owned by third parties) and incident data are also used. For the historic database, TomTom uses GPS measurements only. This historical data covers major motorways, regional, state and local highways, arterials and many local streets of 41 countries worldwide, including South Africa (Louw, 2014). TomTom's historical traffic database comprises a very large sample size, continually amassed by millions of drivers. TomTom has collected probe data since 2007, and more than one billion measurements are collected worldwide every day. The data is thus not dependent on specific survey samples, nor is it vulnerable to inclement weather conditions on one or two surveyed days, for example. The database is also primarily filled with information received from passenger vehicles as opposed to delivery fleets or goods vehicles, which means that the traffic and travel conditions on the road network are unrestricted by speed limiters. Furthermore, FCD has the advantage that it is more representative (it is not limited to point-located roadside infrastructure for communication, and hence provides information on the entire road network) and / or less expensive (no hardware installation and maintenance necessary) than most current data collection devices and techniques; and as a non-infrastructure solution, it avoids the predicaments of theft / vandalism, communications, power and collisions.

Four routes were analysed over different time periods. The routes were:

1. The R44 corridor defined in ***Section 4.2.1*** and shown in ***Figure 4.1***,

and the three main alternative routes from the R44 / Van Reede intersection to the Dorp / Piet Retief intersection:

2. via R44 and Dorp St,
3. via Van Reede Rd, Koch Rd and Piet Retief St, and
4. via Van Reede Rd, Vrede Rd and Piet Retief St.

For the R44 corridor, the time periods were the base period (00:00 to 06:00 – free flow) and three potential morning peak hours (06:45 to 07:45, 07:00 to 08:00 and 07:15 to 08:15). The peak period was evaluated again only by looking at this route. The other three routes were analysed alone over the peak hour (once it was determined) and the base period. The output data for each time period is an average of all the data collected on all Tuesdays to Thursdays of February and March 2015 (i.e. a typical day). It was ensured that all sample sizes were adequate. Where the sample size was below 20 for the comparative time periods and below 10 for the base period, it was clearly stated and comparisons were made to the previous years to assess the correctness of the output. The attributes extracted from the XLS output file are listed in ***Table 4.2***. The 85th percentile is a major parameter used by traffic engineers and transport planners when setting speed limits. For the peak-hour analysis, only travel speed and cumulative travel time were studied. But, once this peak hour was determined, all attributes were examined for all routes over the hour and compared to free-flow.

Speed profiles for free-flow travel conditions and the three potential peak hours along the R44 corridor were drawn by plotting the average speed (per segment) of the time period against the distance along the route (the end position of each segment, measured as a distance from the starting point). Cumulative-time graphs were drawn in the same way, but using cumulative travel time as the dependent variable instead of travel speed. The delays were calculated by subtracting the free-flow cumulative travel time from the cumulative travel time of the peak hour.

4.4.2.1 HISTORICAL DATA PROCESSING – HOW TOMTOM DOES IT

TomTom processes raw GPS data to protect the privacy of the customers, remove inaccurate measurements from the dataset and create the geographic databases made available to third parties. The most important part of this process is map-matching, where the GPS points are matched to a digital map using a map-matching algorithm. Here, each GPS speed measurement is assigned to a

Table 4.2: Parameters extracted from the probe data XLS output.

Parameter	Road section	Definition
average travel speed	entire route, and per segment	distance travelled divided by total travel time
15th percentile travel speed	entire route	speed at or below which 15% of all vehicles are observed to travel past a specific point
85th percentile travel speed	entire route	speed at or below which 85% of all vehicles are observed to travel past a specific point
cumulative travel time	entire route	total time taken to traverse the entire route
average travel time	per segment	time taken to traverse a segment
average travel time delay	entire route	difference between actual travel time and travel time during free-flow or off-peak conditions
15th percentile travel time	entire route	maximum time taken by 15% of all drivers to traverse the entire route
85th percentile travel time	entire route	maximum time taken by 85% of all drivers to traverse the entire route
average travel time ratio	per segment	peak average travel time for the segment divided by free-flow average travel time for the segment

road segment with the highest possible confidence level. The algorithm studies the path of consecutive GPS points in a journey file to define the path of a vehicle. The map-matcher throws out points that could not be matched to a map (due to, for example, changes in the road infrastructure, the use of a GPS device outside a vehicle, etc.), detects u-turns and GPS signals lost in tunnels. When the map-matching is done, an aggregated geographic database (geobase) of measured travel speeds is produced. These geobases are updated regularly for each map of each region or country to take into account the growing historical GPS speed database, as well as updates and changes in / to the road network. This digital map with attached speed information is used as a source for all the historical traffic products.

There are two alternative methods within the Custom Travel Times tool to aggregate multiple FCD journey files to calculate travel times and travel speeds for specified routes. These are:

1. using FCD only from vehicles that traversed the entire route under scrutiny, and
2. using probe data from every vehicle traversing any of the road segments along the route being studied in the required time period.

Both aggregation methods have their benefits and drawbacks. The method TomTom implemented in Custom Travel Times uses fully completed trips on the route where available, and, where necessary, supplements them with data from trips that only traversed part of the route to improve the accuracy and confidence of the data. TomTom, therefore, combines the methods to salvage the advantages of both. The method also leaves out measurements that could be different due to turn dependency at intersections. In this way, the product is using as much data as possible while limiting the over / under estimation of the 'worst case' scenarios.

A limitation of the probe data is still that the data outputs cannot be easily validated, since the individual probe readings are unavailable. Confidence is, however, placed in TomTom that the data processing process is done as meticulously as discussed above.

4.4.3 TRANSPORTATION MODELLING - PTV VISUM 15 AND HCM 2010

Transportation modelling is a scientific process used to understand and quantify prevailing as well as future transportation and traffic conditions. The quantification refers to, for example, capacity constraints, LOS and system efficiencies. Future conditions relate to changes in land-use patterns and growth, a new or upgraded transportation network or an analysis of alternative interventions. Transportation planning models can be divided into three levels based on network detail and geographic extent:

1. microscopic,
2. mesoscopic, and
3. macroscopic.

Microscopic modelling is applied when the required network detail is high and the geographical area is small. The opposite is true for macroscopic modelling. Mesoscopic models are used when medium network detail is required and the geographical area is also medium-sized. The author classifies the model of this research project to be mesoscopic. Various commercial software packages exist that help create transportation models. The four-step model is a common demand forecasting technique integrated into these software packages. The student used the *PTV Group Visum 15* simulation package, because of the partnership the *SSML* has with *PTV Group*. Other software, such as *Emme* (from *INRO)* and *Aimsun* (from *Transport Transportation Systems)*, could also have been used, however.

A base model of the study area was created to determine its prevailing traffic conditions. All the steps that were followed to do so are explained in the subsequent subsections. Whilst the traffic volume study and probe data provided information with regards to the existing traffic volumes on the network during the morning peak hour and what the average travel speeds (and average travel times) are, the studies alone could not analyse the performance of the entire network or individual intersections. A main focus area of this research project was to forecast the traffic conditions that future scenarios will bring about. A transportation modelling tool was the most suited for this. Whilst it can of course determine the above parameters (from traffic volume counts and probe data), the base model was essentially developed so that it could be calibrated while observed data was still available.

4.4.3.1 CREATING THE NETWORK

The network was created by importing geospatial data from OpenStreetMap (OSM). OSM differs from other mapping services such as Google Maps and Bing Maps in that it allows the user to access and edit data behind a map tile. The imported network comprised of the network objects nodes and links, as well as associated turns. The student had to check all the default attributes and make changes where required. Unnecessary nodes and links were deleted, and some additional nodes and links had to be created. The Visum version file (.ver) with all the network objects can be found on the attached CD. ***Table 4.3*** lists all the objects that form part of the network (with the total number of existing objects per object type given in brackets) along with their definition / function. It also shows for which attributes the default values were accepted and for which attributes the default values had to be edited in some cases.

For the nodes, z-coordinates were required so that the model could determine the slopes of the links, which in turn were needed for the calculation of pollution emissions. These coordinates were taken from *Google Earth*. The control types at the intersections also had to be defined. A selection based on the control type in the real world was made between *uncontrolled*, *two-way stop*, *two-way yield*,

Table 4.3: The network objects in the Visum model with their definition / function and attributes.

Network object	Definition / function	Default attributes accepted	Default attributes changed
Nodes (85)	- specify the location of intersections or merging links. - are the start and end points of links. - connect zones with the network.	number, x-coordinate, y-coordinate, capacity, free-flow turning time (t_0)	z-coordinate, control type, method of impedance at node, geometry
Links (196)	- a directed edge, i.e. both directions of a link are independent network objects and thus can have different attributes. - connect nodes and thus describe the structure of the road.	name, number, from node, to node, type, length, HGV share (%)	capacity, free-flow travel speed (v_0), number of lanes, permitted transport systems, environment (urban or rural), volume-delay functions
Turns (232)	- specify which movements are permitted at a node.	from node number, to node number, via node number, capacity, free-flow turning time (t_0)	permitted transport systems
Zones (18)	- describe the positions of utilities in the network (e.g. residential areas and educational institutions). - are origins and destinations of movements within the transport network. - connected to the transport network through connectors.	number	name, x-coordinate, y-coordinate, method for connector share
Connectors	- connect zones to the link network. - represent the distance to be covered between a zone's centre of gravity and the connector nodes.	from node, to zone, length	permitted transport systems
Main nodes (5)	- several nodes can be aggregated to one main node. - using main nodes is useful when intersections consist of several nodes.	same as for 'node'	same as for 'node'
Main turns (49)	- main turns are created when using main nodes. -- each movement via a main node is represented by a main turn.	same as for 'turn'	same as for 'turn'

signalised, *all-way stop* and *roundabout*. For each signalised intersection a signal timing and phasing plan had to be entered. The Stellenbosch Municipality made these available to the student, and they can be viewed on the attached CD. Although the signalisation is semi-actuated during the AM period, a pre-timed plan was entered using the maximum green times. Moreover, the method for calculating the impedance at intersections had to be chosen. The *Intersection Capacity Analysis* (ICA) method was selected, which performs the calculation according to the HCM. Whilst a method was specified, the blocks that needed to be selected for the calculations to actually be performed were not selected for the time being. The reason for this is given in ***Section 4.4.3.5***. Lastly, changes to the geometry of the major intersections had to be made. These changes mainly encompassed adding pockets (additional lane space) to the various approach lanes. The default turning capacities and free-flow turning times of 100000 veh/h and 0 min, respectively, were accepted.

For the links, the default link type had to be checked and edited where necessary. The link types included in the model (primary, tertiary and residential) are listed in ***Table 4.4***. A link type has a default value for the number of lanes, the capacity and the free-flow speed. The transport systems (TSys) permitted on the links also had to be defined. The reason for keeping the default of HGV (heavy goods vehicle) share (%) at 0 is given in ***Section 4.4.3.3***. Only the TSys CAR was thus permitted. For the emission calculation, the environmental setting (urban or rural) had to be specified per link, and then the value for a user-defined attribute, namely *observed volumes*, had to be entered for each link. This attribute was a requisite for the sake of calibrating the model, which is discussed further in ***Section 4.4.3.4***. The final step was the definition of the volume-delay (VD) functions per link type. The travel time of a link is a function of its saturation, which results from its loaded traffic volume and capacity. The free-flow travel time t_0 of a link can be determined from the length of the link and the free-flow speed v_0. In a loaded network, however, the travel time t_{cur} is determined by these so-called VD functions that describe the correlation between the current traffic volume q and the capacity q_{max}. Various forms of the VD relationship exist. The most popular are the Bureau of Public Roads (BPR) formulations, and the conical congestion function. The equation for the classical BPR function, which was applied in the model, is given in ***Equation 4.2***. The BPR function was used, because the parameter b of its equation is an input to the extrapolation procedures described in ***Section 4.7.9***.

$$t_{cur} = t_0\,(1 + a \times sat^b\,) \tag{4.2}$$

where

$$sat = \frac{q}{q_{max} \times c}$$

and

q	=	current traffic volume on the link in the loaded network
q_{max}	=	traffic volume capacity of the link
t_{cur}	=	current travel time of the link in the loaded network
t_0	=	travel time of the link during free flow
a, b, c	=	user-defined parameters; a and $c \in [0;\infty]$, b $\in$ [0;10]

Table 4.4: The link types in the Visum model.

Link type	Link name	Default capacity (veh/h)	Default free-flow speed (km/h)
31	Primary, 2 lanes	2600	100
50	Tertiary, 1 lane	800	70
51	Tertiary, 2 lanes	1600	70
70	Residential	400	50

The recommended values for the user-defined parameters vary greatly in literature. The student was advised by E. Roux, a PTV certified trainer, to apply the following parameters to South African roads:

a	=	0.15
b	=	6, for road classes 1 and 2
	=	4, for road classes 3 to 5.
c	=	0.75

Turns have the attribute *TypeNo*, which is either 1 (right-turn), 2 (through-turn), 3 (left-turn) or 4 (U-turn). The permitted transport system CAR had to be specified at each turn. In the case where no turn movement is allowed (e.g. a one-way), no permitted transport system was assigned. Again, the default turning capacities and free-flow turning times of 99999 veh/h and 0 min, respectively, were accepted.

All zones had to be created. In the model a zone either represents a utility in the network or an area before or beyond an entry / exit link of the network. The locations of the 18 zones within the network are shown in ***Figure 4.4***. The zones are listed with their utility in ***Table 4.5***. Each zone is connected to the network through one or more connectors that join to nodes. For each connector, the permitted transport system CAR had to be specified. The method for connector-share was kept at the default setting at all the zones besides zone 8 - the only zone that connects to the network via numerous connectors. Here, the private transport (PrT) volumes entering and exiting the network are shared by the connectors (i.e. no absolute volume is carried by a single connector).

Main nodes were created at the five intersections that comprise several nodes. These main nodes are located at the following intersections:

1. R44 / Trumali Rd,
2. R44 / Van Reede Rd,
3. R44 / Saffraan Ave and Doornbosch Rd,
4. R44 / Dorp St, and
5. Piet Retief St / Suidwal Rd.

The associated main turns were edited as explained for ‘turns’.

4.4.3.2 CREATING THE O-D MATRIX

The process of creating an origin-destination (O-D) matrix is called *trip distribution* and forms the second step in the traditional four-step transportation forecasting model. It follows after *trip generation* - the first step of the four-step model where the trips that will begin or end in each traffic analysis zone are determined from socioeconomic data. In this research project, because the study area is small, the trips generated per zone were obtained from the traffic volume counts, however. Trip distribution matches the trip makers’ origins and destinations to develop a matrix of numbers that represent the number of trips from each origin to each destination. Each number in the matrix is denoted by the symbol T_{ij} – trips made from origin i to destination j. Instead of using methods such as the gravity model or the Fratar method, the trip distribution step was also performed differently: proportions of turn movements were multiplied by each other to obtain the O-D matrix. This was believed to be much more accurate and doable for such a small network. It was only important to know the volumes on all the links and at all the turns; it was not entirely relevant who made these trips.

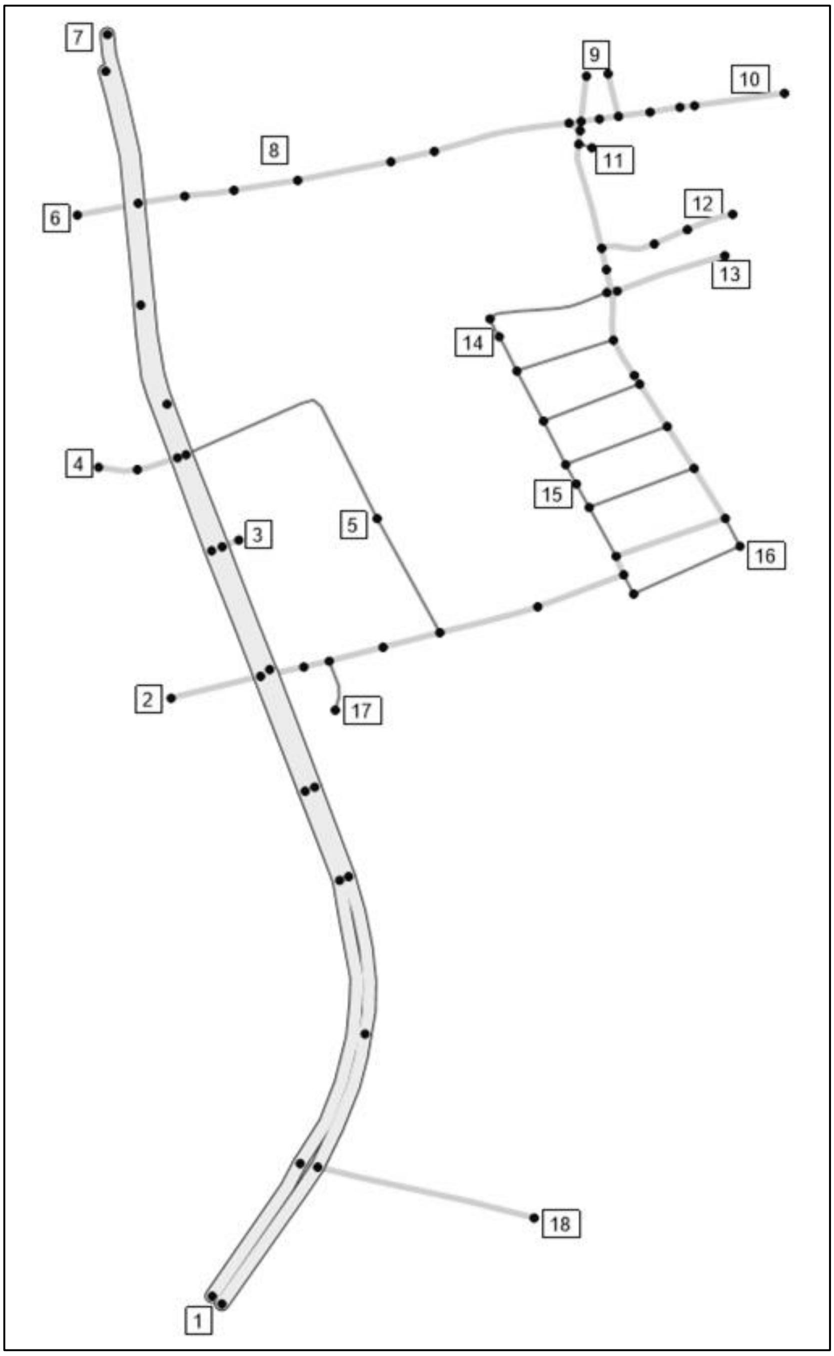


Figure 4.4: The Visum network showing the location of the 18 zones.

It was stated in ***Section 4.4.1.1*** that the turn volumes for each approach at the minor intersections were calculated as proportions of the approach volumes, and that these proportions were then multiplied by the produced approach volumes observed for the major intersections. These turn-movement proportions were in fact calculated for every single permitted turn movement in the network.

An empty 25-cell by 25-cell matrix was created in Microsoft Excel. The reason it is 25x25 and not 18x18, is because some of the zones were split into subzones. Zones 5, 8 and 13 had the following respective subzones: 5a, 5b, 8a, 8b, 8c, 8d, 13a and 13b. These zones have more than one entry / exit, and the subzones made it easier to keep track of which trips had been accounted for when filling the matrix. The matrix was first filled with proportions that were later multiplied by the productions of

Table 4.5: The 18 zones of the Visum network.

Zone number	Name of utility
1	R44 Upstream (before Trumali Rd)
2	Die Boord 1 (Van Reede Rd)
3	Doornbosch
4	Die Boord 2 (Saffraan Ave)
5	Doornbosch Rd
6	Lower Dorp St (towards R310)
7	R44 Downstream (beyond Dorp St)
8	Herold Rd, Papegaai Rd, Mark Rd & Herte Rd
9	Mill St and Bird St
10	Upper Dorp St (beyond Bird St)
11	Stelkor parking
12	Noordwal-Wes Rd
13	Suidwal Rd
14	Bloemhof Girls' High School / Koch Rd
15	Rhenish Girls' High School / Koch Rd
16	Dalsig (Piet Retief St)
17	Dalsig (Barry Rd)
18	Trumali Rd

each zone. To explain how the matrix was filled, zone 1 will be used as an example. From zone 1 it is possible to go to all the other zones in the network. To determine the proportion of zone 1's productions that goes to zone 2, for example, for each route a trip maker can choose to take to get to zone 2, the proportions of turn movements at every node along the route were multiplied by each other and the totals of each route were then added. Route options to zone 2 include, for example, the direct route, but the option also exists to do a U-turn opposite zone 3. Referring to ***Figure 4.5***, the formula for these routes thus is [0.948 x 0.101] + [0.948 x 0.608 x 0.027 x 0.029] = 0.096 = proportion of zone 1's productions that go to zone 2. It is, however, also possible to go once around the whole network along different routes before turning into zone 2. These routes also had to be considered and contributed a further trip proportion of 0,001. This multiplication and adding process was completed for each O-D pair in the network. The sum of all the trip proportions from each zone to all the other zones (i.e. the sum of the proportions of every row in the matrix) finally had to add up to 1. For certain O-D pairs many possible route combinations exist, however, and the formulas got very long. The student stopped looking for possible route combinations when the row totals exceeded 0.95. It must also be remembered that although the turn proportions multiplied by are rounded to three decimal places, they are still rounded numbers in some cases, and thus a total of exactly 1 for the rows will never be reached.

Once the matrix of trip proportions was compiled, the trip proportion for every O-D pair was multiplied by the trip production of each particular origin to form the trip distribution matrix. This matrix still needed to be balanced, however. The total number of trip productions from every zone and the total number of trip attractions to every zone (as observed from the traffic volume counts) did not equal each other. It is standard practice in the four-step model to then assume that the total trip productions are correct, and trip attractions are altered accordingly. Here, the total trip productions were 8129 and the total trip attractions 8205, resulting in a difference of 76 trips. The trip attractions per zone were thus reduced by a factor of 8129/8205. Referring back to the fact that the row totals did not add up to exactly 1, the values in the trip distribution matrix still needed to be adjusted, so that all rows (productions) and all columns (attractions) added to the known amounts. This was done manually.

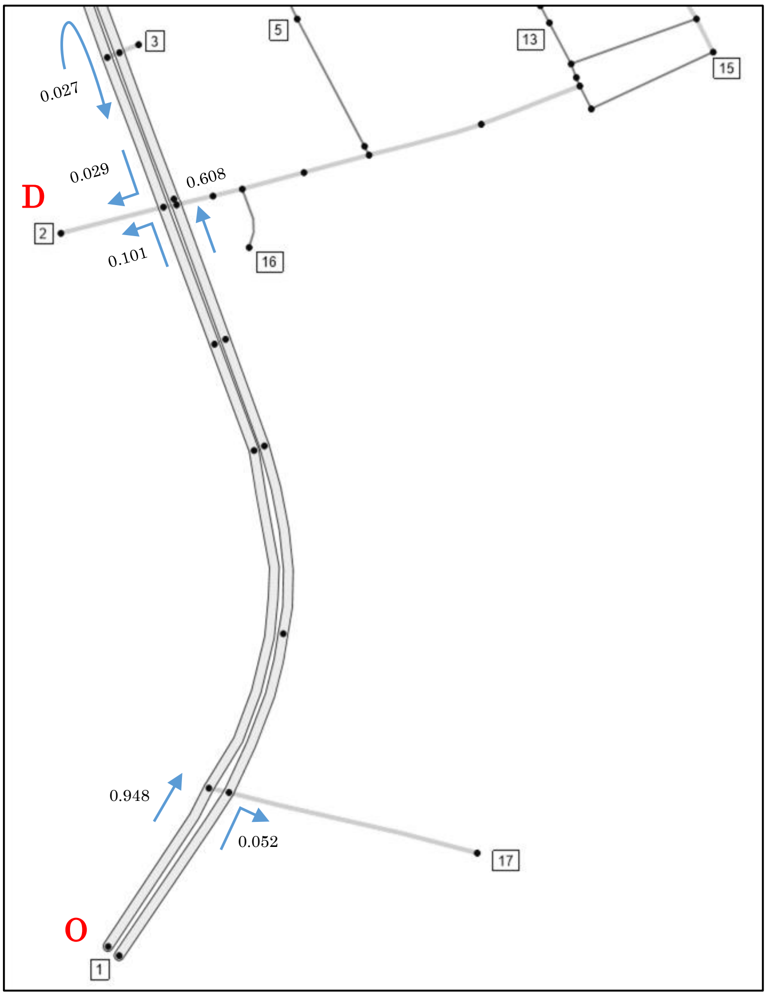


Figure 4.5: Proportion of observed turn movements along the route from zone 1 to zone 2.

The observed link volumes from the traffic count study helped decide to which O-D pair trips should be added.

4.4.3.3 ASSIGNING THE O-D MATRIX

In Visum, demand segments provide the link between transport supply and traffic demand. Transport supply comprises several transport systems, which have the properties *transport system type* (e.g. private transport or public transport) and *means of transport* (e.g. car). Traffic demand refers to the O-D matrix. In short, a demand segment is assigned one mode and exactly one demand matrix. For each mode, several demand segments can be defined though to differentiate between population groups, for example. In this research project no such differentiation is made, however, and all road users form part of the same demand segment.

For the assignment of the O-D matrix, the demand segment *C Car* was created. This demand segment was then allocated to the mode of transport *car*. This is taken as step three of the four-step model (*mode choice* – defining the mode trip makers use to travel from one zone to another). All vehicle trips in the study area were taken to be of the transport system type *PrT* and the means of transport *car* without applying passenger car equivalents (PCE). As alluded to in ***Section 4.4.1.1***, from the traffic volume study it was evident that the HGV modal share in the network is insignificant, and it thus seemed acceptable to make this simplification. During the peak hour when the road network is congested, HGVs in any case do not act as speed limiters. It should be noted though that HGVs remained accounted for in the fleet composition applied during the environmental impact analysis, and HGVs were also included in the calculation of vehicle operations costs (see ***Section 4.4.1.3.7*** and ***4.6.3.1,*** respectively).

The next step was to create the 07:00-to-08:00 time series that defined the analysis period, and then assign the O-D matrix to the demand segment *C Car*. In the *procedure sequence* when the procedure *PrT Assignment* was created, the demand segment *C Car* was allocated to it as the reference object. Finally, the assignment variant had to be specified. The student chose to use *equilibrium assignment*. This distribution model assigns demand according to *Wardrop's first principle*: a road user selects the route that offers him / her the lowest disutility in terms of travel time, travel cost, reliability, safety and other elements. In this research project, impedance during assignment is only a function of the travel time on the links (see ***Section 4.4.1.3.5)***, where impedance equals one hundred times t_{cur} (the default setting). In literature, the equilibrium assignment distribution model is more specifically referred to as *Individual Equilibrium (IE)* or *User Equilibrium (UE)*. The assignment determines a user optimum that differs from a social or system optimum. The *Social Equilibrium (SE)* distribution model, based on *Wardrop's second principle*, arranges traffic so that the overall network runs under the lowest disutility. In summary, *user optimum* means that the same disutility results for all the routes of a traffic relation between zones *i* and *j*, and that changing to another route is not profitable to any trip maker. Under *social optimum* lower disutilities usually arise per trip maker, but there are some trip makers that use routes with disutilities above average to serve the general public.

The user equilibrium state can be formulated by ***Equation 4.3***.

$$min! \sum_{a \in E} \int_0^{q_a} R_a(x)dx \tag{4.3}$$

subject to

$$q_{ijr} > 0, \forall ijr$$

$$\sum_r q_{ijr} = q_{ir}, \forall ij$$

$$\sum_{ijr : a \in P_{ijr}} q_{ijr} = q_a, \forall a$$

$$\sum_{a \in E_u^+} q_a - \sum_{a \in E_u^-} q_a = \sum_i q_{iu} - \sum_j q_{uj} = D_u - O_u, \forall u$$

where

E	=	set of all edges (i.e. links) in a network
a	=	one specific link
q_a	=	volume on link *a*
R_a (x)	=	impedance of link *a* with volume *x*
q_{ij}	=	the total demand (number of trips) from zone *i* to *j*.
q_{ijr}	=	volume on route *r* from zone *i* to *j*
P_{ijr}	=	route *r* from zone *i* to *j*
E^+_u	=	the set of incoming links at node *u* (network nodes and zones)
E^-_u	=	the set of outgoing links at node *u*
D_u	=	destination traffic at node *u*
O_u	=	origin traffic at node *u*

The equation shows that the sum of impedances of all the links is minimised, while the secondary conditions indicate that:

1. all path volumes have to be positive;
2. the volumes on all of the routes from zone i to j have to add up to the total demand from i to j ;
3. the volume on a link results from the sum of the trips on all of the routes that make use of this link; and
4. flow conversation applies at each node. When a node corresponds with a zone, the difference between the volumes on all incoming links and the volumes on all outgoing links have to correspond precisely with the difference between the destination and origin traffic. Since there is no origin or destination traffic at the network nodes, the difference must be zero there.

Due to the non-linearity of ***Equation 4.3***, the solution is attained by means of iteration. It can be shown that as long as $\frac{\partial R_a(x)}{\partial x} \geq 0$ for all a, the problem converges to a unique solution. The equilibrium assignment procedure with its individual steps is shown in ***Figure 4.6***.

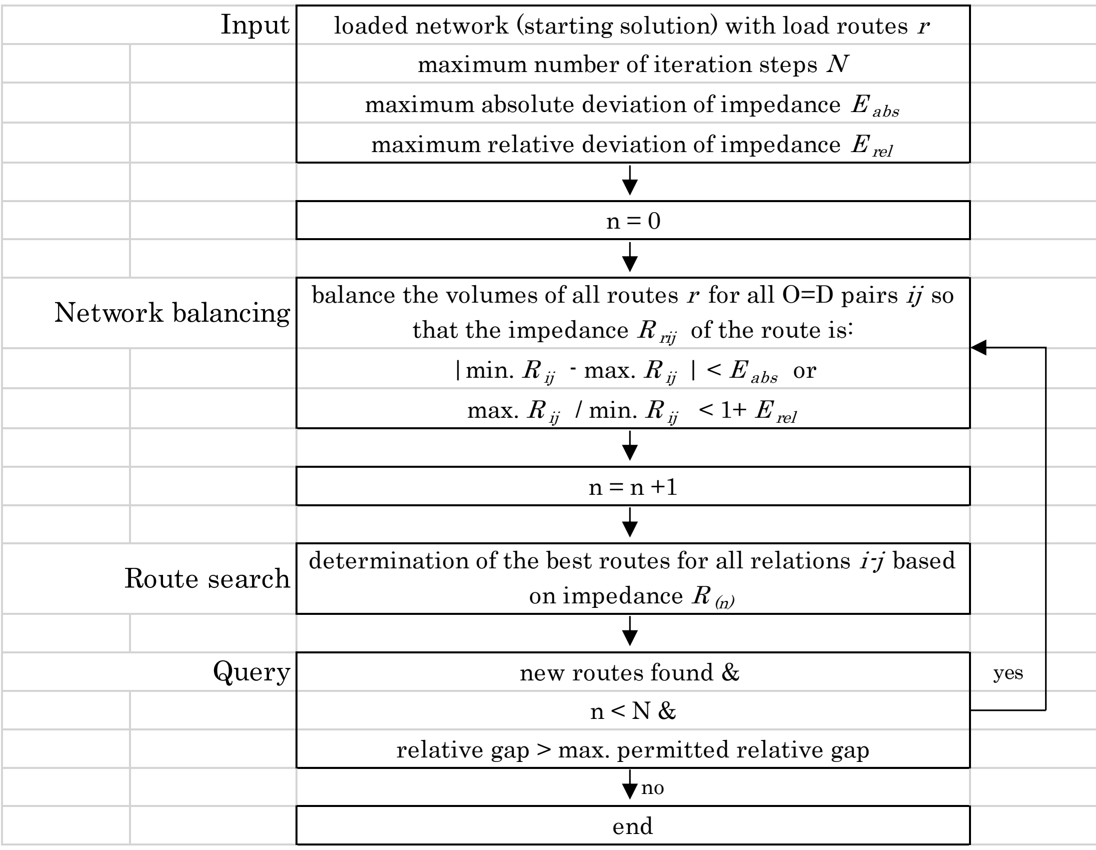


Figure 4.6: The equilibrium assignment procedure. Source: PTV Visum 13 Manual.

Based on an assignment result of a previously calculated assignment, or an incremental assignment (by default), as a starting solution, the state of balance is reached by multiple steps of iteration. In the inner iteration step, two routes for an O-D pair are brought into a state of equilibrium by shifting vehicles. These iteration steps are carried out for all O-D pairs until these relations are in a state of balance. Every shift of vehicles from one route to another has an immediate effect on the impedance of the traversed network links. The outer iteration step checks if new routes with lower impedances can be found as a result of the current network state. If this is the case for at least one O-D pair, another state of balance is calculated.

Visum terminates the iteration process when one of the following conditions have been fulfilled:

1. network balancing has been achieved (i.e. a permitted deviation of impedances of the routes compared in pairs was reached or undercut), as shown in ***Figure 4.7***;
2. the specified number of external iterations was reached without reaching a balanced network; or,
3. the convergence criterion *Max. Gap* is reached and undercut.

Maximum gap is the measure of the weighted volume difference between the current loaded state and the hypothetical vehicle impedance, which is the minimum impedance value calculated hypothetically for the next iteration step on the assumption that all vehicles - based on the current impedances in the network - use the best path.

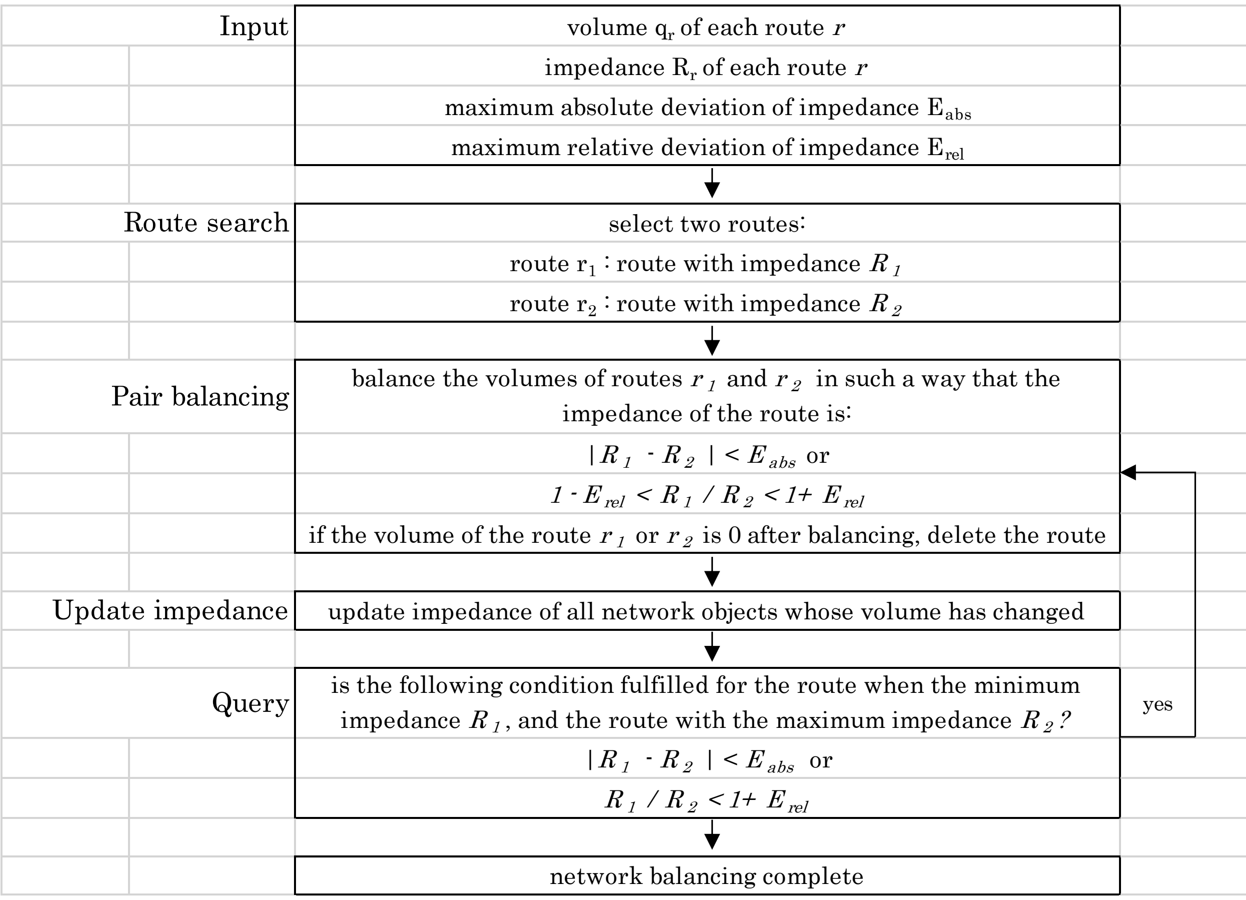


Figure 4.7: The network balancing procedure for an O-D pair during equilibrium assignment. Source: PTV Visum 13 Manual.

Equilibrium assignment was chosen above incremental assignment, because its property of only terminating when all routes of any O-D pair are in the balanced state produces more accurate results. The incremental assignment procedure models how a network continuously fills up. At the beginning, trip makers can use a free network for which exactly one shortest route exists for every O-D pair. The traffic network is then successively loaded. Every step congests the road network with additional vehicles and, in this way, increases the impedance on the congested links and turns. Because of the changed impedance, alternative shortest routes may be found in every step. In incremental assignment, already assigned trips cannot be shifted, however. Stochastic assignment was also considered as an alternative to equilibrium assignment. The stochastic distribution model, likewise, assumes that trip makers choose the travel route with the lowest disutility, but furthermore assumes that individual routes are evaluated differently due to incomplete and different information. More routes are loaded in the case of stochastic assignment, because parts of the demand are assigned to suboptimal routes as well. This property is generally closer to reality than the application of Wardrop's first principle. In the model, however, the combination of equilibrium assignment and demand matrix calibration proved to provide a better picture of reality than stochastic assignment for which demand matrix calibration cannot be run without the report of an error at some point or another.

In the model, incremental assignment was selected for the initial solution calculation nonetheless, with an O-D demand share of 33% for the first iteration step, another 33% for the second step, and 34% for the third. This means that Visum calculated the impedances of the current network and carried out a so-called best-route assignment before the equilibrium assignment procedure began. A maximum of 20 iterations and a maximum gap of 0.0001 was inputted as the termination condition for the equilibrium assignment, and a maximum of 5 iterations was set for network balancing.

Executing the procedure, i.e. assigning the trips to the network, concluded the four-step model. It was then not only known from where to where trips go, but also which routes travellers take to get there.

4.4.3.4 GOODNESS-OF-FIT MODELS AND MODEL CALIBRATION

The GEH statistic and the coefficient of determination (denoted as R^2) were used to represent the goodness-of-fit of the base model. The GEH formula, named after its inventor Geoffrey E. Havers, is an empirical formula that is widely used for a range of traffic analysis purposes. Although its form is similar to that of the chi-square test, it is vital to note that it is not a statistical test. The formula compares two sets of traffic flows by taking into account both the absolute and the percentage difference between the modelled flows and the observed flows from the traffic-volume-count field studies. This is better than simply using percentages to compare the two sets, because traffic volumes within a network can vary over a wide range, and selecting a single acceptable percentage of variation is therefore not possible. The GEH statistic for a link is computed as shown in ***Equation 4.4***.

$$GEH_j = \sqrt{\frac{2(O_j - M_j)^2}{O_j + M_j}} \tag{4.4}$$

where

O_j = observed traffic flow (veh/h) on link / turn *j*

M_j = modelled traffic flow (veh/h) on link / turn *j*

The GEH value is not unitless; it has the unit $(veh/h)^{0.5}$. A GEH of less than 5.0 is considered a good match between O_j and M_j. According to the UK Highway Agency's Design Manual for Roads and Bridges, 85% of the volumes in a traffic model should have a GEH less than 5. The PTV model was calibrated until this condition was met.

The coefficient of determination, is an additional statistical measure that was applied to assess how well the modelled volumes matched the observed volumes. A R^2 of 1 indicates a perfect match, while a R^2 of 0 indicates a very poor match. An acceptable values typically lies between 0.7 and 0.9. The value of R^2 was calculated using the *RSQ( )* function in Microsoft Excel. The formula behind this function is as shown in ***Equation 4.5***.

$$R^2 = \frac{SSE}{SST} = \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y}_i)^2} \tag{4.5}$$

where

SSE	=	Error Sum of Squares
SST	=	Total Sum of Squares
y_i	=	observed volume
$\hat{y}_i$	=	modelled volume
$\bar{y}_i$	=	mean of the observed volumes

The Visum model was calibrated using the *Demand matrix correction (TFlowFuzzy)* procedure, which adjusted the original O-D demand matrix so that it matched the real supply that was observed. A detailed description of the methodological basics of *TFlowFuzzy* is not given here, but can be found on page 212 of the PTV Visum 13 Manual. In every iteration, the procedure compared the results of the pre-calculated assignment to the counted volumes of the links, as well as the turns and main turns, and a new demand matrix was formed. This procedure was set to repeat twenty times, whereafter the final O-D matrix was obtained.

4.4.3.5 IMPEDANCE / DELAYS AT THE NODES

The *UseMethodImpAtNode* function that calculates the impedance at a node was kept unchecked during the trip assignment procedure for very specific reasons. During the assignment with ICA in oversaturated networks, the model limits the inflow on the links; it does not allow the volume passing from one link to another to exceed the capacity of the link, nor does it allow the queues on a link to exceed the stocking capacity of the link. These constraints unnecessarily complicate demand matrix correction when observed volume counts are available, as was the case in this research project. This means that at all the nodes and turns, t_{cur} equalled t_0 (set to equal zero), and only the impedances on the links were thus considered during the iterations of equilibrium assignment. Only after the trip-assignment and demand-matrix-correction procedures were done, was an ICA calculation executed (one at a time) at each node and main node that is controlled either by signalisation, a roundabout or two-way stop. The analysis was performed over a one-hour analysis period that coincided with the AM peak hour that was previously defined. This approach implicitly assumed the arrival rate of vehicles within the hour to be constant throughout. Time did not allow for dividing the one-hour analysis period into four 15-min analysis periods and then determining the control delay at every node for each of the periods and for every scenario described in ***Section 4.5.2.2***. The PHFs at all of the intersections suspected to cause the greatest delays ranged from 0.88 to 0.97, with most of the PHFs falling into the upper limit of this range. These high values were taken as an indication that the one-hour-analysis-period approach was acceptable to use.

The standard formats of the ICA reports for signalised intersections, roundabouts and two-way stops, respectively, are presented in ***Appendix D.4*** as ***Tables D.1, D.2*** and ***D.3,*** along with the formula for each of the input parameters. The LOS criteria for these three control types are given in ***Tables 4.6*** and ***4.7***. The methodologies for calculating control delays for the three control types, respectively, are taken directly from chapters 18, 19 and 21 of the HCM 2010, and are thus not repeated in detail in this write up. Although the calculations were set to be done according to the HCM 2010, some of the layouts of the steps follow the HCM 2000 more closely. An arrival type 3 was assumed for all of the signalised intersections: *"random arrivals in which the main platoon contains less than 40 per cent of*

Table 4.6: LOS criteria for signalised intersections.

Control delay (s/veh)	LOS by volume-to-capacity ratio	
	≤ 1.0	> 1.0
≤ 10	A	F
> 10 – 20	B	F
> 20 – 35	C	F
> 35 – 55	D	F
> 55 – 80	E	F
> 80	F	F

Table 4.7: LOS criteria for roundabouts and two-way stop intersections.

Control delay (s/veh)	LOS by volume-to-capacity ratio	
	≤ 1.0	> 1.0
≤ 10	A	F
> 10 – 15	B	F
> 15 – 25	C	F
> 25 – 35	D	F
> 35 – 50	E	F
> 50	F	F

the lane group volume". Since the ICA reports only contain values (no formulas), and some minor errors were found in a few of the reports, formulas were entered into the ICA reports for the base case. These reports were then copied for all the other scenarios, so that only changes to the base volumes (plus some other minor changes where necessary) had to be made in order to obtain the new delays.

For all control types, the impact pedestrian movements had on the control delay was ignored, because it was rarely observed that traffic was delayed as a result of pedestrian movements alone. On the tertiary and residential roads, the pedestrians could simply walk through the stationary traffic. At the signalised intersections, very few pedestrian calls were made with the actuated push button. The only pedestrian crossing that was not ignored was the one at Paul Roos. The frequency of the pedestrian calls was recorded along with the signal timings. A pattern was observed for the majority of the hour and therefore, a pre-timed signal plan could be derived. This is the only 'intersection' for which the ICA calculation was eventually set to be performed during the assignment procedure, as it helped profusely in more accurately assigning vehicle trips to all the side streets in Krigeville. Also, at the Van Reede / Doornbosch intersection, it is near to impossible to get out of Doornbosch and a traffic officer assist traffic flow there every morning. The 'phases' were timed and an approximate average delay was applied for each of the turn movements.

Once the control delay for every movement at every intersection had been calculated, the values were entered back into the model as t_{cur} for all the permitted turns. This was repeated for every scenario.

4.4.3.6 PERFORMANCE MEASUREMENT OF THE NETWORK

The future objective of the model was to measure the performance of the network for the project alternatives described in ***Section 4.5***. In Visum, performance measurement can be divided into one of two types:

1. performance measurement for the defined O-D pairs, and

2. performance measurement for the entire network.

The former is calculated with skim matrices and the latter using global indicators. User-developed performance measures can of course also be done by examining the attributes of individual network objects and, for example, adding them to study the performance of a specific route.

In this research project, the three most important model outputs were:

1. Vehicle Miles Travelled (VMT) in the AM peak hour. VMT is calculated from the total number of vehicles in the network and the distance (in km) that they travelled.
2. Vehicle Hours of Travel (VHT) during the AM peak hour. VHT is computed from the product of a link's volume and its travel time, summed over all of the links.
3. Mean system speed for the AM peak hour. The mean system speed is the quotient of VMT and VHT.

These outputs, more specifically VHT and mean system speed, served as the inputs to the equations that quantified the traffic conditions in monetary terms, i.e. the value-of-time and vehicle-operating-cost equations, which in turn were needed for the CBA. VMT, VHT and mean system speed are all global indicators. VMT and VHT were automatically calculated during the execution of the *Assignment Analysis* procedure. The procedure had to be executed two times: once for the links and once for the turns. The results for each were then summed to get the total VMT and total VHT. The same results could have been obtained with the execution of the *Calculate PrT skim matrix* procedure, and then adding the results of all the O-D pairs.

As mentioned in ***Section 4.4.1.2,*** probe data was applied to evaluate the average travel speeds and travel times of the three main alternative routes from the R44 / Van Reede intersection to the Dorp / Piet Retief intersection. The *Calculate PrT skim matrix* procedure was used to determine the same two attributes for the same three routes for the base case, so that a comparison between the probe data results and the Visum model results could be made for this case. Since the modelled results were used for all the other cases, this verification of the base-case results was very important. The paths of the O-D pairs do not directly match those of the three routes. The travel time on some specific links thus had to be subtracted or added from / to the travel time for an O-D pair.

Given that the mobility benefits had to be determined not only for the entire network, but also for the main routes that some commuters will continue to use in all of the alternatives, the individual travel speeds and travel times had to be evaluated for these routes for all of the scenarios. The routes comprised the probe data routes, but also the combination of paths of the 1-6, 1-7, 1-9, 1-10, 1-12 and 1-13 O-D pairs. The calculations were done in the same way as described above for the probe-data validation.

In addition, the performance of the major intersections was measured. Because the volume-to-capacity, control-delay and LOS calculations had already been done for all of the intersections, the measurement of performance merely comprised an analysis of these results. Although the traffic conditions had to be monetised for the CBA, an improvement or deterioration in traffic conditions is often made sense of better when expressed in units of speed and / or time. That is why the measurement of performance for the intersections was done only in terms of these units.

4.5 PROJECT ALTERNATIVES

Three project alternatives were evaluated as part of this research project. Unquestionably, the theoretical implementation of a bicycle-sharing scheme for school and university destined commuter traffic in Stellenbosch was one of these. This alternative would not have been worth much without an alternative to compare to. This is why the *null alternative* – the *do-nothing option* was so important. The other project alternative was evaluated as a supplement, to put the results of the CBA for the bicycle-sharing scheme into further perspective. At a time when this research project was already well underway, the municipality began with the geometric improvement - capacity enhancement - to the R44 / Van Reede intersection. It thus seemed appropriate to include this geometric improvement as a project alternative.

4.5.1 NULL ALTERNATIVE: DO-NOTHING OPTION

This research project can be looked upon as a "with-and-without" comparison. What will the level of traffic congestion be in Stellenbosch in the future if bicycle-sharing is implemented for school and university destined commuter traffic, or any other traffic congestion improvement project is employed for that matter? And, what will the traffic congestion be like without any implementation of such sort?

The null alternative is a continuation of the existing conditions with no money invested for upgrades. It is an evaluation of the normal traffic growth that would have occurred in spite of an improvement to the current infrastructure. Normal traffic growth refers to the increase in the traffic volume on a specific link or combination of links due to the general increase in the number and usage of vehicles in that zone and / or surrounding zones. A normal traffic growth rate is typically attributable to the following factors that are not necessarily independent of each other: a change in land use, a general population growth, an increase in the per capita ownership of vehicles, an increase in the average user per vehicle, a gross domestic product (GDP) growth, and / or an increase in fuel price. Historic traffic data can also aid in predicting future traffic growths. It should be mentioned though that short-term traffic volume counts are generally considered inappropriate to use for the determination of traffic growths due to their inaccuracy in representing the average annual daily traffic (AADT); counts from permanent stations should be used instead. A comprehensive analysis of the future traffic growth rate for the town of Stellenbosch fell outside the scope of this research project, but several of the factors mentioned above were investigated.

As stated in ***Section 1.1.2,*** the general population growth for the Stellenbosch Municipality between 2001 and 2011 was 2.75%. The growth in the SU student population for the Stellenbosch campus only was examined from statistics on the number of enrolments per faculty for the years 2005 to 2014, and was found to be 3.27% (Stellenbosch University, 2015). In the Western Cape Government 2014 Budget Summary, the economy of the province was forecasted to grow at an average rate of 3.4% between 2013 and 2018. In the 2015 Budget Summary, however, the province's economy was forecasted to only grow at an average rate of 2.7% between 2014 and 2019. Furthermore, annual traffic growth rates from historic traffic data were studied for the major intersections in the study area for which historic counts were available, and analysis of probe data over a five-year time span was performed. The results are given in ***Chapter 5***.

Traffic growth is calculated using the formula given in ***Equation 4.6***. It should be noted again though, that all of the comparisons entailed the analysis of single one-day counts, whose accuracy in representing the traffic volume of an average day in the year is questionable.

$$i = \sqrt[n]{\frac{V_n}{V_0}} - 1 \tag{4.6}$$

where

i	=	average annual traffic growth rate
n	=	number of years for which i is evaluated
V_n	=	traffic volume after n years
V_0	=	traffic volume in the base year

Once a growth rate was defined, this growth rate was applied to each O-D pair of the base-model matrix to get the new null-alternative O-D matrices. The new node-delays were determined by multiplying each turn volume in the formulated base-model ICA reports by this same growth rate. The new link-delays were computed in Visum by multiplying the *c* parameter of the VD functions with the inverse of the growth rate. The null-alternative VMT matrices were calculated by simply applying the growth factor to the base-model VMTs. This assumes that there is no change in the equilibrium distribution of the vehicles in the network in future years. The VHT matrix was determined using the *Calculate PrT skim matrix* procedure, as explained for the base model. All null-alternative travel costs were calculated as for the bicycle-sharing alternative, described in ***Section 4.5.2*** and again in ***Sections 4.6*** and ***4.7***.

4.5.2 BICYCLE-SHARING ALTERNATIVE

A broad overview of the 'whys' and 'hows' of the theoretical bicycle-sharing scheme for school and university destined commuter traffic in the town of Stellenbosch, to be implemented as a sustainable mode of transport to relieve traffic congestion, was discussed in ***Chapter 1***. This alternative is about the evaluation of the potential benefits and costs of such a scheme, compared to the null alternative – staying with the current mode. The economic evaluation procedure is defined in this subsection, and the different scenarios for which the benefits and costs were evaluated are described. The user-cost and economic factors adopted and applied for the overall evaluation are also defined. The methodologies behind the determination of the potential project costs, revenues and benefits (benefits to authorities, remaining road users, bicycle-share users, and society as a whole) are discussed in later subsections.

4.5.2.1 SELECTION OF THE ECONOMIC EVALUATION PROCEDURE AND THE DESCRIPTION OF THE LEVEL OF DETAIL

A traffic network assignment model combined with a link based user-developed procedure was used to simulate and test the impact of a decrease in traffic volume in the study area. For the case study of this research project, the direct benefits to each bicycle-share user and the remaining road users are borne only on the route traversed by this user, and a link based approach was hence appropriate here. The indirect benefits to society and the benefits to authorities, however, extend beyond a specific route, and could therefore not be evaluated with a simple link based method; here, a network analysis was called for.

The benefits for all alternatives were modelled explicitly for the AM peak hour. It is not only the scope of this research project that did not allow for an analysis of the benefits for all hours of the day and all days of the week; it is also an idealistic thinking to work in such a way. The level of detail for all the analyses performed in the AM peak hour was high due to the small study area that was selected, and since many of the input variables were actually calculated and not simply adapted from other projects and reports. It is generally during the peak period that operating conditions are the worst, vehicle operating costs the highest, and therefore, potential cost savings the greatest. So, although the benefits of the AM peak hour had to be interpolated to the other hours of the day for which less information was known (so that a more accurate BCR analysis can be performed), it was seen to that the level of detail was high for the period in which the greatest benefits would be achieved.

4.5.2.2 DESCRIPTION OF THE SCENARIOS

The likely uptake of this alternative mode of transportation is dependent on the scope of the marketing scheme as well as the amount of support / backing the schools and university will be willing to offer (i.e. will the scheme be integrated into a school travel plan that is to be strictly implemented?). As a result, benefits will be presented for a varying number of users, taken as percentages of the total number of potential users calculated. A range of scenarios was also tested to determine the influence that key variables have on the benefits and costs of the scheme. These variables were:

1. scheme size (relates to costs),
2. ridership (relates to benefits),
3. fare structure (relates to revenue potential),
4. and operational model (relates to costs).

The different scenarios could only be decided on once the theoretical bicycle-sharing scheme for Stellenbosch had been designed. It was impossible though to test all the modifications in separate scenarios, because too many scenarios would have arisen; the modifications had to be grouped, and still not all combinations of the modifications could be tested. The modifications are shown in ***Table 4.8*** in terms of the four variables mentioned above. The various scenarios also account for the occurrence of a gradual uptake of cycling (not all at once as assumed for the CBA).

The modifications for the size of the scheme comprised designing for varying percentages of the total potential users. For ridership, different proportions of the total-potential-user number that would use the scheme were tested. Once the fare structure had been defined, the effects of a 10% increase as well as a 10% decrease of the fares were evaluated. In terms of the operational-model variable, the point of scenario management was not to test totally different models (e.g. manual vs. automatic). Once an operational model had been decided on, the idea was simply to test the change in project costs and benefits when those components that are perhaps considered 'luxury' are removed. Reducing project costs at the expense of quality was seen as pointless, because it would result in an unsuccessful, underutilised implementation. It was decided from the beginning that rather no bicycle-sharing scheme should be implemented than one that is sub-standard and drives people away from cycling forever. The 'luxury' components are identified in ***Section 9.6.6.***

Table 4.8: Description of the modifications for the bicycle-sharing alternative.

Base Case / Modification	Scheme size	Ridership	Fare structure	Operational model
B1	-	-	-	-
B2	school learners - bicycles for all potential users	-	-	-
B3	SU students - bicycles for all potential users	-	-	-
B4	SU staff - bicycles for all potential users	-	-	-
B5	-	school learners – all potential users* cycle	-	-
B6	-	SU students - all of potential users* cycle	-	-
B7	-	SU staff - all of potential users* cycle	-	-
B8	-	-	as calculated	-
B9	-	-	-	all components included
M1	school learners - bicycles for 75% of potential users	-	-	-
M2	SU students - bicycles for 75% potential users	-	-	-
M3	SU staff - bicycles for 75% potential users	-	-	-
M4	school learners - bicycles for 50% of potential users	-	-	-
M5	SU students - bicycles for 50% potential users	-	-	-
M6	SU staff - bicycles for 50% potential users	-	-	-
M7		school learners - 75% of potential users* cycle	-	-
M8		SU students - 75% of potential users* cycle	-	-
M9		SU staff - 75% of potential users* cycle	-	-
M10	-	school learners - 50% of potential users* cycle	-	-
M11	-	SU students - 50% of potential users* cycle	-	-
M12	-	SU staff - 50% of potential users* cycle	-	-
M13	-	-	10% increase to B8	-
M14	-	-	10% decrease to B8	-
M15	-	-	-	exclude 'luxuries'

*the proportions refer to the number of users for which the system was designed, i.e. they relates to the *scheme size* modifications.

The combinations of modifications, i.e. scenarios, that were tested are given in ***Appendix A.2, Table A.1***. The following rules were applied whilst defining these scenarios:

1. Bicycle-sharing for SU students was only available when bicycle-sharing for school learners was already in place, and bicycle-sharing for SU staff was only available when bicycle-sharing for US students was already in place.
2. When bicycle-sharing for SU students was included in a scenario, the same scheme size % and same ridership % for school learners and SU students were combined. The same applied when bicycle-sharing for SU staff was included.
3. A scheme designed only for 50% of the potential users was not combined with a ridership of 50%, because only small benefits would be reaped from this combination.

For all of the scenarios, no provision was made for likely vehicle trips generated by the new facility (either bicycle-sharing or additional lanes). These are trips that would not have been made if the new facility had not been provided. It was also assumed that, for all of the scenarios, the remaining road users will continue to take the routes they are currently taking.

4.5.2.3 TOOLS AND INPUT

The inputs that were required for the bicycle-sharing methodologies, and the tools that were employed to obtain these inputs, were made known clearly in ***Figure 4.3,*** and are discussed in detail in ***Sections 4.5*** to ***4.9***. The user-cost-factor inputs that were required for some of the methodologies are specified in the succeeding subsection.

4.5.2.4 USER-COST FACTORS

The user-cost factors are the constant values, independent on traffic flows and network performance, that are used in the benefits analysis for all project alternatives and all scenarios. For this research project the factors are: value of time (VOT), vehicle occupancy and the costs of accidents.

4.5.2.4.1 VALUE OF TIME

"The value that [road] users assign to their travel time will depend upon the opportunity cost of that time, and the consumption opportunities that the users associate with travelling." (AASHTO, 2010) This opportunity value is attributed to one hour of a road user's time, and is expressed in ZAR/h. Since work is an alternative use of time, especially in the commute travel context, the opportunity value is normally linked to an hourly, after-tax wage rate. Other determinants, such as mode and distance as well as distance, have also been used. In this case study, however, no differentiation between the VOT for motorists and cyclists was made.

The User and Non-User Benefit Analysis for Highways manual (AASHTO, 2010) recommends the following VOTs:

- Driver alone commute → 50% of wage rate
- Carpool driver commute → 60% of wage rate
- Carpool passenger commute → 40% of wage rate

In the Netherlands, an hour lost by an employee in traffic is also calculated as half of the average hourly salary (Buis *et al,* 2000). In South Africa, on the other hand, a proportion of 0.25 for the wage rate is often used. As a result of these differences, the sensitivity analysis was performed. A proportion of 0.5 was assumed for the start.

As the statement above suggests, VOT varies for different road user types and / or trip purposes. School learners have a VOT that differs to that of their parents (with differences also between parents), and SU students again have a different VOT to SU staff.

The average VOT of the school learners was taken as zero. In the surveys distributed to the school parents, the parents were asked to give their household's annual income. These specified incomes were used to first compute the average income of all the households, and then determine the VOT of the school parents (see ***Table 4.9)***. The income range relates to the income groups that the respondents could choose from and the frequency refers to the number of responses received for each of these groups. It was assumed that there are 250 working days in the year and 8 working hours in a day. The average hourly wage for the school parents (per household) is ZAR384.47. The VOT thus is ZAR190.00, with rounding. It was assumed though, that this VOT only applies to 0.25 of the drivers who drop their children at school. For the other, i.e. non-working, parents and SU students, the per capita income of South African citizens was applied. This income was calculated by adding the last four quarterly national nominal GDP estimates given in the respective quarterly GDP reports, compiled by Statistics South Africa, and then dividing the sum by the total South African population (see ***Table 4.10)***. This value was then furthermore divided by the total number of hours in a year to determine the VOT; no further proportion of 0.5 was applied. With rounding, the answer came to ZAR8.00/h. The average VOT of SU staff was calculated from the average salaries of SU employees taken from PayScale (updated 4 July 2015) and shown in ***Table 4.11***. The average hourly wage for SU staff (assuming an equal proportion of commuters for each job) is ZAR116.27, which, with rounding, results in an average VOT of ZAR60.00/h. For the other commuters on the road network, i.e. the general commuters, this same VOT was applied, as it seemed like a fair balance between the low per capita average income and the high average income of the school parents.

Table 4.9: Average income calculation for the school parents of Bloemhof Girls' High School, Paul Roos Gymnasium and Rhenish Girls' High School.

<table>
<tr><th>Income range</th><th>Mid-value, u_i</th><th>frequency BGHS, f_{BGHS}</th><th>f_{PRG}</th><th>f_{RGHS}</th><th>f_{total}</th><th>$f_{total} \times u_i$</th><th>avg.</th></tr>
<tr><td>ZAR0 to ZAR100k</td><td>ZAR50k</td><td>4</td><td>13</td><td>7</td><td>24</td><td>ZAR1,2 mil</td><td rowspan="6">ZAR768,931 (annual)

ZAR384.47 (hourly)</td></tr>
<tr><td>ZAR100k to ZAR350k</td><td>ZAR225k</td><td>48</td><td>48</td><td>25</td><td>121</td><td>ZAR27.23 mil</td></tr>
<tr><td>ZAR350k to ZAR650k</td><td>ZAR500k</td><td>55</td><td>105</td><td>35</td><td>195</td><td>ZAR97,5 mil</td></tr>
<tr><td>ZAR650k to ZAR1.3 mil</td><td>ZAR975k</td><td>79</td><td>147</td><td>52</td><td>278</td><td>ZAR271,05 mil</td></tr>
<tr><td>more than ZAR1.3 mil</td><td>ZAR1,5 mil</td><td>34</td><td>62</td><td>11</td><td>107</td><td>ZAR160,5 mil</td></tr>
<tr><td>total</td><td></td><td></td><td></td><td></td><td>725</td><td>ZAR557,48 mil</td></tr>
</table>

To summarise, the following VOTs were applied in this research project to monetise travel time (with VOT = 0.5 × hourly wage):

- School learners → ZAR0.00/h
- Working school parents → ZAR190.00/h
- Non-working school parents and US students → ZAR8.00/h
- SU staff → ZAR60.00/h

Table 4.10: Calculation for the average VOT for all people for all hours of the day, assumed for non-working parents and SU students.

nominal GDP for third quarter of 2014	Gross domestic product, Third quarter 2015 Statistics South Africa	ZAR963 billion
nominal GDP for fourth quarter of 2014	Gross domestic product, Fourth quarter 2015 Statistics South Africa	ZAR979 billion
nominal GDP for first quarter of 2015	Gross domestic product, First quarter 2015 Statistics South Africa	ZAR975 billion
nominal GDP for second quarter of 2015	Gross domestic product, Second quarter 2015 Statistics South Africa	ZAR991 billion
2015 mid-year population estimate	Statistics South Africa	54.96 million people
per capita annual income of SA citizens	ZAR71,106	
hours in a year	$365 \times 24 = 8760$ hours	
Avg. VOT for all people for all hours of the year	ZAR8.12	

Table 4.11: Average hourly wage calculation for SU staff (PayScale, 2015).

Job	Salary range	Mid-value salary	Avg. salary
Lecturer	ZAR140,688 to R476,167	308,428	ZAR232,534 (annual) ZAR116.27 (hourly)
Office administrator	ZAR78,105 to R313,481	195,793	
Researcher	ZAR114,059 to R460,879	287,469	
Research Assistant	ZAR62,860 to R214,031	138,445	

4.5.2.4.2 VEHICLE OCCUPANCY RATE

As should be clear from the previous subsection, travel time savings are evaluated per road user and not per vehicle. An average vehicle occupancy rate was therefore required. A value of 1.46 passengers per vehicle was calculated from the responses to the lift club questions asked in the SU survey (see ***Table 4.12***). This question was not directly included in the school-learner questionnaire, so the vehicle occupancy results calculated for the SU trips were also employed for the school trips. A sensitivity analysis was performed with an average vehicle occupancy of 1.2, because it is believed that many of the other, general commuters travel alone.

Table 4.12: Vehicle-occupancy-rate calculation.

Vehicle occupancy	Frequency, f	Vehicle occupancy $\times f$	Avg. vehicle occupancy
1	172	172	1.46
2	27	54	
3	13	39	
4	10	40	
5	4	20	
6	1	6	
Total	227	331	

4.5.2.4.3 ACCIDENT COSTS

The accident cost rates shown in ***Table 4.13*** were applied in the accident-savings calculations. The values were originally specified by the National Institute for Transport and Road Research (1999), which is now CSIR Transportek. Prof. CJ Bester of the SU department of Transportation Engineering has updated these values every year to account for inflation of the private transport operation group.

Table 4.13: 2015 accident cost rates applied in the accident-savings calculations.

Accident type	Cost (ZAR)
Fatal injuries	1,2 million
Seriously injured	275,000
Slightly injured	72,000
Damage only	47,200

4.5.2.5 ECONOMIC FACTORS

4.5.2.5.1 DISCOUNT RATE

For the net-present-value technique described in ***Section 4.9.2.1***, a discount rate was required to bring all future costs back to a present-worth. A real interest rate (= nominal interest rate – inflation rate) was used. It was thus assumed that an equal inflation applies to all of the components of the scheme and that the nominal interest rate is affected by that same inflation rate. A value of 3% was used for the discount rate, because The World Bank specified that the real interest rate for South Africa in 2014 was 3.1%, and also because the User and Non-User Benefit Analysis for Highways manual (AASHTO, 2010) suggests a 3% discount rate when inflation was removed in the evaluation of costs.

4.5.2.5.2 BASE / EVALUATION DATE

From the Cycling Plan, introduced in ***Section 1.2.2***, it is understood that it will take about 5 years to make safe provision for cycling. To reap the full benefits of a bicycle-sharing scheme and attract many users from the start (users who are not disappointed after making the shift to this alternative mode of transportation as a result of the scheme not having reached its full potential), it was decided to set the launch date of the scheme to 2020, which is five years from now.

It is important to note though that the base date, also referred to as the evaluation date, was set to be 2015. The base date is the date to which all costs and benefits are discounted, whatever the future periods are in which they are expected to occur, so that they can be expressed and compared in a common unit. The base date was set as 2015, i.e. today, based on the assumption that the relative scarcity of the resources used in the supply and operation of the bicycle-sharing scheme will not change over the five years (i.e. that differential inflation will not occur). Inflation could thus again be disregarded, because the year in which the costs were evaluated and the time of the evaluation of the benefits is the same. It was thus required, however, to apply the traffic growth rate calculated for the null alternative to current traffic volumes, because benefits were only evaluated from the year 2020 based on the traffic conditions then.

4.5.2.5.3 INFLATION RATE

As discussed in the previous two subsections, inflation was not considered in this research project.

4.5.2.5.4 SERVICE LIFE

Based on the life of the scheme's equipment and the facility life of the Drop-and-Go zones and Park-and-rides (see ***Section 10.2)***, the service life of the scheme was set as 15 years, i.e. benefits and costs of the scheme were evaluated over a 15-year period. The costs and benefits per bicycle-share user were calculated on a per-year.

4.5.2.5.5 RISK

Risk and uncertainty in the evaluation of the research statement were handled in two ways:

1. risk was incorporated directly in the estimation of the costs and benefits by making use of physical contingency values; and
2. a sensitivity analysis was performed for the parameters about which there was uncertainty (incl. the discount rate).

A risk-free discount rate could thus be used.

4.5.2.5.6 VALUE OF A STATISTICAL LIFE

The methodology used to evaluate health benefits, required the value of a statistical life (VSL) as an input (see ***Section 4.7.7)***. The standard value of a VSL is derived using a method of willingness to pay. Transportation planners often prefer VSL as the measure for valuing health or a life, but other measures also exist. These include: cost of illness, years of life lost, quality-adjusted life-years, and disability-adjusted life-years.

The default in HEAT for VSL is EUR 2.59 million for the WHO European Region (OCED, 2012). In South Africa, the economic value attached to a human life is determined from the lost production of an individual caused by death. This value is a lot lower than that just mentioned for Europe. The average discounted lifetime value of an average person is ZAR 420,387 in 2006 prices (ZAR 313,315 for the middle-income group and ZAR 1.31 million for the high-income group). The source is unknown, but the values were given to the student by a professor of the SU Transport Economics Department. Using the current headline CPI annual inflation rate of 4.6% (Statistics South Africa, 2015), the approximate average 2015 value for all income groups is ZAR 630,136 (ZAR 469,641 for the middle-income group and ZAR 1.96 million for the high-income group). The remaining lifespan of all the individuals in all the income groups is approximately 30 years. A value of ZAR 1.0 million for the economic value of a human life was applied in this research project as an input to the health-benefit calculation, because the likelihood of the school- and university-graduates to earn well is predicted to be high, and also because the average lifespan of the individuals is higher than 30 years.

4.5.3 GEOMETRIC IMPROVEMENT TO R44 / VAN REEDE INTERSECTION

The geometric improvement to the R44 / Van Reede intersection is a capacity enhancement comprising the construction of additional lanes on the southern and eastern approaches. The geometry of the intersection before and after the implementation of the improvement is shown in ***Figure 4.8*** and ***4.9,*** respectively. The construction is being done in stages. To date, the construction of the additional lanes on the eastern approach (phase 1) has been completed, with phase 2 - the double right-turn lanes on the southern approach - to follow in the next few months. The figure does not depict this very well, but the left-turn lane on the eastern approach was changed into a slip lane. The cost expenditure for phase 1 was R3.37 million (excl. VAT), which included 3x11kV high voltage electrical cables, the relocation

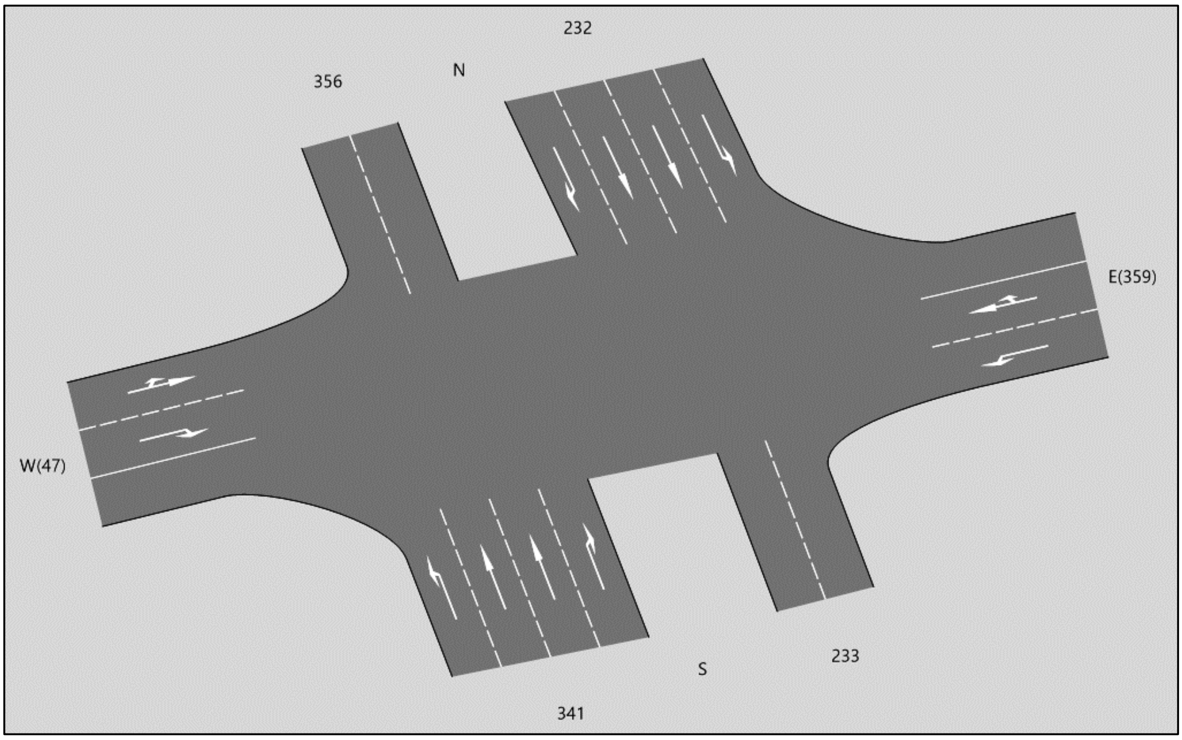


Figure 4.8: Geometry of the R44 / Van Reede intersection before capacity enhancement.

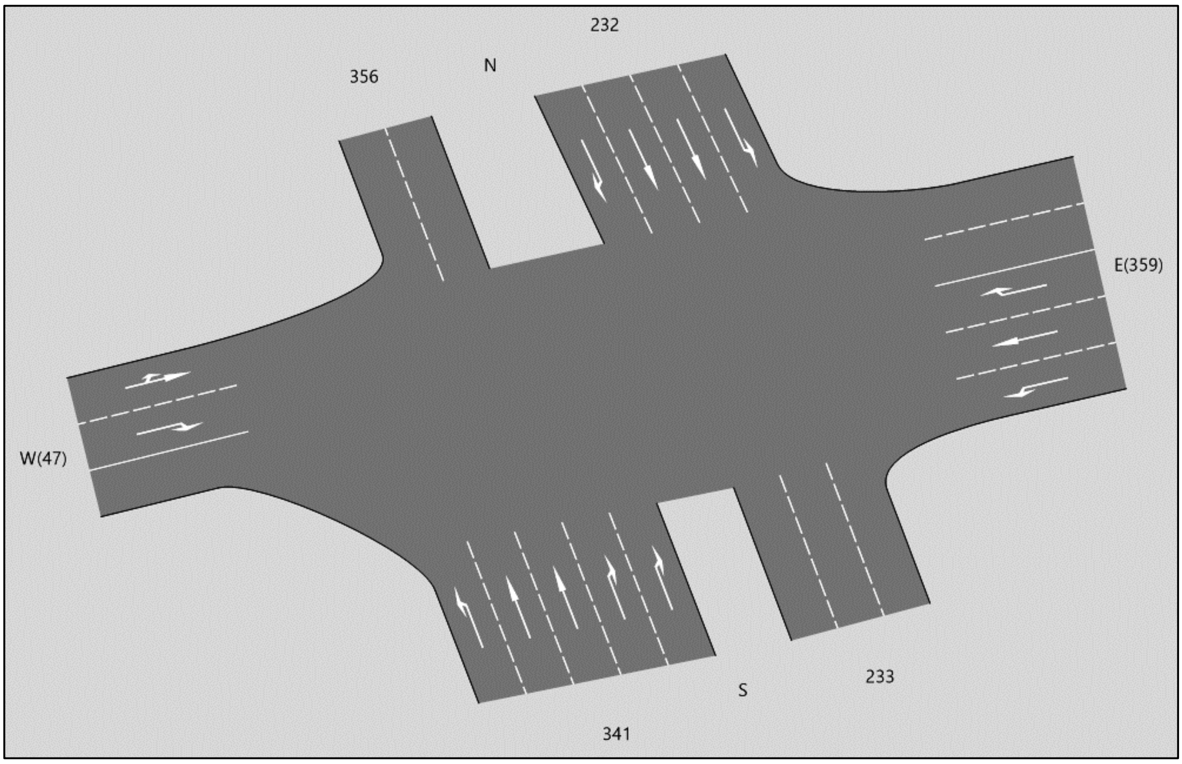


Figure 4.9: Geometry of the R44 / Van Reede intersection after capacity enhancement.

of street lighting and the replanting of four trees. The estimated construction cost for phase 2 is ZAR 1.2 million (excl. VAT). The total cost of the project thus is R4.57 million. (Stellenbosch Municipality, 2015)

The primary benefits from additional lanes derive from the changes in travel time and operating costs, if the changes to accident frequencies, and ultimately accident costs, are ignored. Because the increase in capacity on this one part of the network is very likely to affect traffic flows elsewhere on the network, the benefits of the additional lanes were evaluated by modelling the entire network. The benefits of travel-time and operating-cost savings were calculated as described for the bicycle-sharing alternative; travel times and operating costs were compared to the null alternative, and the same user-cost and economic factors were applied. A FYRR, NPV and BCR, based on these benefits and the costs described above, was then computed.

For the extrapolation of the benefits to the other hours of the day, it was assumed that the off-peak period and PM-peak period together reap the same benefits again. In other words, the AM benefits were doubled to get the total benefits of the intervention for the day.

This alternative was included to evaluate the effectiveness of the municipality's current action plans regarding traffic congestion. The question to be answered, was whether one can build one's way out of traffic congestion after all?

It must be noted that bicycle-sharing alternative is thus based on the geometry of the network before the construction of the capacity-increase began.

4.6 BICYCLE-SHARING PROJECT COSTS

4.6.1 PROJECT COSTS

There is not much of a methodology behind the evaluation of the project costs. The costs for all the scenarios of the scheme, as outlined in ***Figure 3.4*** were determined from online research, the Bill of Quantities (BoQ) and reports of already-implemented projects, requested and received quotations, as well as information collected via e-mail correspondence and during personal interviews with engineers from the industry. The results of the literature review were used to compare and verify the order of magnitude the evaluated costs. The cost analyses were not only performed after the project design phase, but also during this phase, to rule out certain operational models and approve others.

The overall project costs were divided into four categories:

1. construction costs (of the Drop-and-Go zone and the Park-and-Ride),
2. equipment costs,
3. launch and implementation costs, and
4. running costs.

The construction and equipment costs together make up the capital costs.

The right-of-way costs, more commonly referred to as real estate costs (cost of the land needed to develop the scheme), were not included in the costs analysis. The monthly insurance premiums of the scheme were also not included.

The total construction cost was the one that was determined from an existing BoQ. This document is confidential and only totals could be extracted. For this cost, a contingency of 5% on the total estimate was included to account for the uncertainty in the approximations derived from multiplying certain costs by a ratio of the areas. The construction cost will be an up-front cost that is not to be subjected to any discounting, because a short construction period is expected. The construction costs did not encompass the construction of any bicycle facilities or infrastructure, such as cycle paths, that did not directly form part of the scheme. Since the construction costs of bicycle facilities were not included, the maintenance of these facilities, of course, also did not form part of the cost analysis.

All costs are given in ***Chapter 10*** along with references, where available.

4.6.2 COSTS TO THE POTENTIAL BICYCLE-SHARE USERS

The only cost considered for the potential bicycle-share users was their out-of-pocket cost to use the service, i.e. membership fee. Indirect user-costs, such as comfort and convenience, were not included, and neither was the vehicle operating cost (VOC) or the value of their time spent travelling, because these formed part of the benefit analysis. The CBA was also only performed for the commuters, not other users which will be discussed in ***Chapter 9***.

4.7 BICYCLE-SHARING PROJECT BENEFITS

In this section the calculations behind the evaluation of the bicycle-sharing project benefits are shared. The results are given in ***Chapter 12***, where some methodologies are also described in more detail. Reference is always made to the bicycle-sharing alternative, but the formulas and methods presented here were essentially also used for the null alternative and the geometric improvement alternative. The equations, in fact, only represent benefits when the cost results for the bicycle-sharing and geometric improvements were subtracted from those obtained for the null alternative – the higher and steadily increasing cost conditions at which the traffic would otherwise have travelled.

In addition to determining the total direct benefits to the authorities (for all scenarios), total direct benefits for all scenarios were also appraised per user (road and bicycle-sharing). For each benefit, it was expressed to whom they apply. It was also clearly stated whether a quantitative or qualitative approach was taken. All the given formulas are for the AM peak hour only – the hour of the day in which traffic congestion is at its worst. An extrapolation procedure was then attempted to extrapolate the results for this particular hour to other hours of the day (PM peak hours) and eventually other years of the service life / analysis periods (see ***Section 4.7.9***). The savings for each year were then aggregated to attain the total savings. Only the PM peak hours were included as part of the 'other' hours, because the opportunity to improve average travel times is lower for all the other hours, based on the VD relationship and the fact that only the school learners (and not all) will be cycling back in the early hours of the afternoon. The average VOT is also tremendously lower during the off-peak period.

4.7.1 IDENTIFICATION OF POTENTIAL USERS AND STATION LOCATIONS

The electronic questionnaires on travel characteristics that were distributed to the parents of seven schools in Stellenbosch, as well as a selection of SU students and staff, were introduced in ***Section 1.1.3.2***. The purpose of the surveys, namely to identify the number of potential users for the theoretical bicycle-sharing scheme for Stellenbosch, i.e. the demand, and to identify station locations, was revealed as part of the research design in ***Section 3.3***, and the survey content was also presented there. In this section, it is described how the surveys were distributed, and the methodologies for the potential-user and station-location calculations are given. All of the results are given with confidence intervals, since proportions of the sample were applied to the total population and results can therefore, not be given with 100% confidence. The supplementary data that was collected from the surveys, i.e. data that was not required for these two calculations, are not mentioned in this section, but are reported on in ***Chapter 7*** along with a summary of all the other survey results. The full set of survey responses is provided on the attached CD.

4.7.1.1 DISTRIBUTION OF THE SURVEYS TO THE SCHOOLS

A motive for including only the three high schools in Krigeville in this research project has also been shared. Only the distribution methodology for these three schools is provided here.

A letter addressed to the principals of the schools that provided an overview of the study, i.e. the objective and desired output, and requested the permission to distribute the online link to the research questionnaire, was drafted and personally delivered to the school secretaries (see ***Appendix D.1*** for a copy of this letter). It was stated in the letter that the principals would be contacted shortly to schedule a meeting, which would allow them to obtain more detailed information concerning the survey and ask any questions they may have. A meeting was held with each of the principals shortly thereafter (in the case of Bloemhof Girls' High School, it was the facility manager) during which permission to distribute the link was received. The schools assisted in this activity by sending an e-mail to all the school parents on behalf of the researchers via their internal e-mail distribution lists. The e-mail again comprised a letter (see ***Appendix D.2)*** that explained the research study, and of course the link to the online survey was included. Furthermore, an advertisement for the study was placed in the schools' weekly newsletters. All the information on the research never mentioned bicycle-sharing. It was only stated that the researchers were investigating the characteristics of school travel, its contribution to the town's recurrent congestion during morning peak hours and alternatives that could possibly improve this congestion in the future. The general questions made the data appropriate to use for other transportation studies, such as the feasibility studies of other solutions to traffic congestion.

4.7.1.2 POTENTIAL-USER CALCULATION FOR THE SCHOOLS

Before describing the potential-user calculation, it must be made clear that the calculation determines the <u>potential</u> users, i.e. the number of people who COULD take up cycling, not who WOULD take up cycling.

Feasibility studies for bicycle-sharing schemes that are to be employed for the general public, typically forecast demand by looking at factors such as population density, employment density, GDP, patterns of commuter traffic, mode share and cost per mode, proximity to attractions and landmarks, existing bicycle infrastructure - which links to a safer riding experience, topography, equity, as well as public comments, and assigning weights to these factors. However, since the potential users in this research project stem from two closed environments and the calculation was all about who could cycle, this form of demand forecasting was not necessitated.

<u>The steps of the potential-user calculation for the school learners were as follows:</u>

1. The number of respondents per school that specified their trip origin were counted.
2. For each origin in the south, the number of respondents per school were recorded.
    - From this step forth, only the trips generated in the south, i.e. Paradyskloof, Jamestown, De Zalze, Technopark, Somerset West, Strand, Gordon's Bay and Sir Lowry's Pass, and arriving in Stellenbosch via the R44 corridor were considered in the analysis.
3. From the number obtained in step 2, non-potential users were subtracted.

- Subtractions had to be made from the number of respondents from the south to attain the actual total number of potential users. These subtractions were: (i) learners in the hostel/ boarding house, (ii) learners who make use of a mode of transportation other than the private motor vehicle, and (iii) learners whose parents specified that the private-motor-vehicle trip is *en route* (mostly to work). A further subtraction was made for learners with siblings in Stellenbosch primary schools (in grades other than grade 7). Because here a trip to school by private motor vehicle is made anyway, it is assumed that the convenience of this mode is preferred for and by the high school learners in this case. The parents were also asked whether their child/children would cycle / walk to school if there were no barriers. Whilst some did indicate *"no"*, a closer look into the responses made it clear that these answers were based on distance (too long) in almost all cases. As "*child/children do not like walking / cycling"* was the most uncommon barrier preventing active transportation (see ***Section 7.1.5***), no subtractions were finally made to account for those learners.

4. The total potential users per school were calculated.
   - The remaining total number of respondents per school was divided by the total number of respondents of each specific school (Step 1), and then multiplied by the total learner population of the respective schools to get the total potential users per school.
5. The potential users calculated per school were summed.

From the total number of potential users per school, the capacity of the bicycle docking stations could be established for every scenario.

It could not be said that the total number of potential users equals the total potential number of vehicle trips saved to school every morning, and from school every afternoon, as several of the potential users may currently be travelling together, either because they are siblings or because they are part of the same lift-club. At first, the total number of vehicle trips per school were determined, accounting only for siblings within the same school and lift-clubs composed of learners from the same school. The required information was found in the survey responses. The total number of vehicle trips per school were then summed, and it is from this total that subtractions were made for learners from two or three different schools that travel together. The difference was taken as the total number of potential trips saved every day. For the school learners, it was assumed that all vehicles turn right into Van Reede Rd at the R44 / Van Reede intersection, and that all the trip savings would thus apply to this route.

4.7.1.3 STATION-LOCATION CALCULATION FOR THE SCHOOLS

Again, since the school learners are part of a closed environment for which the trip patterns are known, no complex calculation was required for determining the site location of the bicycle docking stations for the research case study.

The decision on where in the study area to position the Drop-and-Go zone was based on three factors

1. literature on average acceptable cycling distances - as described in ***Section 2.4.1.9,***
2. topography,
3. the point on the R44 corridor where the traffic congestion changes from bad to worse, and
4. the availability of open land.

The same Drop-and-Go zone is to be used by all three schools.

The destination of all the learners (in the mornings) is their respective school. Bicycle docking stations are thus to be located at each of the three schools.

4.7.1.4 DISTRIBUTION OF THE SURVEYS TO THE UNIVERSITY

The survey prepared for the SU students and staff, was distributed in a different manner to the one for the school learners. At the time when the survey for the school learners was compiled, the study area for this research project was not yet known, and hence all the parents were surveyed. When it was time to compile the survey for the SU students and staff, however, the study area was already decided on, based on the results of the school survey. Although the initial plan was slightly different, a survey was sent out only to those students and staff members residing in the southern suburbs / towns of / to Stellenbosch. Along with a formal application for ethical clearance, institutional permission had to be applied for in order to obtain the e-mail addresses for these students and staff members. Both of the applications were approved and hence ethical clearance as well as institutional permission (on a few conditions) was granted (see ***Appendices B.2*** and ***B.3*** *)*. One of the conditions for the institutional permission was that the e-mail addresses could not be provided directly to the researcher, but that they would be inserted into the survey tool (SUrvey) by an authorised person from the SU IT office. Once this was done, the link to the online questionnaire was sent out as part of an e-mail along with an information sheet of the research (see ***Appendix D.3*** *)*.

The initial plan was to simply add questions to the survey the Department of Logistics and Facilities Management developed as part of a mobility study for the Stellenbosch University, and use it to obtain the results for this research project. This proved not to be possible for two reasons: (1) the distribution date of the survey was set to be the end of September at the earliest, which was a problem since this research project was due in November; and more importantly, (2) the survey was very detailed and long, and was to call for personal interviews with each respondent, since it came with a trip diary and mobile application that needed to be carefully explained. This is a tedious process and would only have allowed for a small sample size to be surveyed. There was no guarantee that any students or staff from the study area of this research project would be questioned, or at least that any statistically significant results to this research could be obtained. A separate survey was therefore called for.

4.7.1.5 POTENTIAL-USER CALCULATION FOR THE UNIVERSITY

The potential-user calculation for the SU students and staff straightway began with the subtraction of non-potential users. That is after deleting the responses from the few respondents who indicated that their daily trip to the SU campus does not entail travelling along the R44 from the direction Somerset West. The calculations for the US students and staff were kept separate. It was at least the intention to keep the two datasets separate, but the person who compiled the confidential e-mail lists forgot to do so. The student was quite fortunate though that an error occurred when the survey was distributed for the first time. 458 e-mails failed to send. It was soon realised that the error was due to the fact that whilst many staff members have student numbers, their e-mail addresses do not contain these student numbers, as is the case for students. The survey asks whether a respondent is a student or staff member. After the first distribution of the survey, only a handful of staff members responded; almost all responses came from students (see full survey response sheets on the attached CD*)*. Then, once the e-mail addresses had been corrected, and the survey was distributed to these e-mail addresses only, this time predominately staff members responded. It was only after a reminder was sent out to everyone, that students responded again. It was thus concluded that all of the 458 failed e-mails belonged to staff members, and that all other e-mail addresses belonged to students.

<u>The criteria for non-potential users were as follows:</u>

1. respondents who make use of transportation modes that are not the private motor vehicle;

2. respondents who use the private motor vehicle as their mode of transportation, but do so by sharing a lift with at least two other people;
3. commute to campus after 8am on at least two days of the week;
4. respondents who commute to campus in private motor vehicles, but as passengers and where it was indicated that the trip is *en route* to the driver and not destined to campus; and
5. respondents who gave valid personal reasons, such as health issues, to why they do not and / or cannot cycle to campus.

All the other respondents were taken to be potential users. The proportion of potential users was then calculated for the sample (for students and staff separately), and that proportion was then multiplied by the total number of students and staff residing in the southern suburbs / towns of / to Stellenbosch, respectively, to determine the total number of potential users.

The total number of potential vehicle trips saved was calculated by looking at the number of students and staff that are in a lift club with one other person. Again, a proportion of the sample was calculated and multiplied by the total number of students and staff residing in the southern suburbs / towns of / to Stellenbosch. The two numbers (students and staff) were then divided by two and subtracted from the total number of potential users. The difference was taken as the as the total number of potential trips saved every day. The respondents were asked which way they go once they reach the intersection of the R44 and Van Reede Rd. This information was important, because it could then be determined how many trips are saved on each route on a daily basis.

4.7.1.6 STATION-LOCATION CALCULATION FOR THE UNIVERSITY

The station-location calculation for the university was done much the same way as for the schools (see ***Section 4.7.1.3)***. The decision on where in the study area to position the Park-and-Ride was based on the same three factors, except that the average acceptable cycling distance, specified by the respondents, was also considered. In the survey, the participants were asked what their field of study is. The answer was used to determine the destination of the respondents. The bicycle docking stations were located on campus so that the trip-end walking distance is limited to a maximum of 300m. The required capacity of these stations was calculated from the number of potential users destined to each of the stations.

4.7.2 FUTURE TRAFFIC FLOW

As mentioned when the base date was defined, the traffic volumes for 2020 had to be evaluated for the case study. These were entered into the Visum model as a modification to the base case to determine the project benefits relative to the null alternative (annual traffic growth the end of 2034).

4.7.3 SAVINGS IN ROAD USER COSTS

In the economic context, road user costs comprise vehicle running costs, the value of the travellers' time and accident costs (note: these are not the costs per road user). The vehicle running costs include fuel consumption, tyre wear, engine oil consumption, maintenance costs and capital costs. The financial equivalent to vehicle running costs is VOC, which are traditionally divided into running costs and time-bound costs. Running costs are fuel consumption, tyre wear, engine oil consumption, as well as maintenance and repairs. Time-bound costs, also referred to as standing costs, include driver and crew costs, depreciation, interest, licensing and permits, insurance, as well as garaging and parking.

In this research project, VOCs were calculated at first and then a shadow price factor (see ***Section 4.9.1)*** was applied later to determine the economic value that was required to assess the total vehicle-running-cost benefits to the authorities.

4.7.3.1 SAVINGS IN VEHICLE OPERATING COSTS

The calculation of the total annual VOC costs requires the following inputs:

1. the total VMT during the AM peak hour, and
2. the mean system speed for the AM peak hour.

A formula (see ***Equation 4.7***) for urban areas in the AM peak period that incorporates all the running costs and time-bound costs in one was used to determine VOC. As for the accident costs, the coefficients of the equation were originally specified by the NITRR (1999). Prof. CJ Bester of the SU department of Transportation Engineering updated these coefficients too every year to account for inflation of the private transport operation group. The latest update of the VOC equation was used (June 2014), applying to it the private transport operation CPI annual inflation rate (from June 2014 to June 2015) of -3.0% (Statistics South Africa, 2015). All future VOC costs were also calculated using this equation, because the annual inflation rate for petrol increases and decreases at fluctuating rates.

$$\mathrm{VOC} = 0.00024 \cdot \mathrm{V}^2 - 0.03139 \cdot \mathrm{V} + \frac{41.64323}{V} + 4.87885 \tag{4.7}$$

where

VOC is expressed as a cost per km, and

V = average travel speed of all vehicles (km/h)

The design of a road and the traffic conditions on the road network significantly VOC. It was assumed that these influences are accounted for in the travel speed.

The VOC for the bicycle-sharing alternative was taken to be zero.

4.7.3.2 TRAVEL TIME SAVINGS

The travel-time cost calculation is similar to the VOC calculation, except that the objective is to calculate the cost per passenger, or road user, rather than per vehicle. The calculation is therefore based on an average travel times and a vehicle occupancy rate rather than average travel speed per vehicle. The travel time savings for the bicycle-sharing alternative were evaluated by applying the average VOT determined for the SU to all the road users, and using the individual VOTs only for the per-user benefits and when specific road users were subtracted from the network.

The average travel time for the cyclists was determined from the distance of the cycling route and an assumed average urban cycling speed of 14km/h (used in the WHO HEAT for cycling methodology, see ***Section 4.7.7)***.

4.7.3.3 ACCIDENT COST SAVINGS

In general, accident frequency is a function of a variety of factors. These include the geometric design features of the roadway, traffic volumes, as well as congestion levels. However, in the absence of more detailed information on these factors, accident frequency can be modelled as a function of the volume-to-capacity ratio of the roadway or individual link; an increase in v/c results in an increase in accidents, and *vice versa*. The theoretical bicycle-sharing scheme, which is to reduce the v/c ratios on the links in the study area, thus has the potential to reduce the number of accidents in this area during the peak hours. The extent to which accident costs can be reduced is dependent on the number of accidents that have occurred in recent years. The methodology for determining the likely accident cost savings the bicycle-sharing scheme is able to provide hence began with an investigation of the number of accidents that occurred during the AM and PM period over the last five years, as well as the severity of these accidents. The source of this information was the Western Cape Transport Data Integration Site. The severity of each accident was very important, because the cost of an accident is dependent on this severity. The costs for the various categories of accident severity were given in ***Section 4.5.2.4.3***.

It was initially planned to use the accident prediction model in the Highway Safety Manual (HSM) to predict the safety effects of the bicycle-sharing scheme (and hence assess accident savings compared to the null alternative). AASHTO (2010) describes the HSM as "a multistage, multiyear research project that is intended to be the most comprehensive effort to date for developing tools for evaluating highway safety and predicting the safety effects of highway improvements". The author, however, came across a research paper (Roodt, 2012), which found that the safety performance functions of the model not to be transferable to the South-African context. Based on these findings, the prediction model was not used. By chance, the same R44 corridor was even included in this research paper.

Since no off-the-shelf prediction model was now available, and because the scope of this research did not allow for any detailed analyses of accidents (and road safety in general), a guesstimate had to be made based on the five-year accident record mentioned above.

This guesstimate of the potential accident cost savings for the bicycle-sharing alternative was only made for the entire network; no savings to individual road users were evaluated.

Although also a factor to look at in future, there was no easy of foreshadowing the number of bicycle accidents that could come with an increase in cycling. But it is known, that the total amount of bicycle-related injuries increase with an uptake of cycling, but at a lower rate (Jacobsen & Rutter, 2012).

4.7.4 OTHER MONETARY SAVINGS

Although probably insignificant, an annual vehicle registration (with the university) cost is saved by the SU students if the shift to the bicycle is made. These parking-cost savings were expressed based on the 2015 value of ZAR 288 and applying to it the September 2015 (same as August 2015) headline CPI annual inflation rate of 4.6% (Statistics South Africa, 2015) every year.

4.7.5 SLOWED PAVEMENT DETERIORATION

It was assumed that even if all potential bicycle-share users were to take up cycling, the effects on a slowed pavement deterioration would be minimal, as other vehicles, and especially heavy vehicles, would continue to traverse the roadway from which some vehicles were removed. These effects were thus not accounted for.

4.7.6 SAVINGS IN ENVIRONMENTAL COSTS

Only CO_2 emissions were considered during the analysis of environmental savings. CO_2 emissions were calculated for the null alternative and all the scenarios of the bicycle-sharing alternative from the mean fuel consumption of the network. As explained, the fuel-consumption cost itself forms part of the VOCs. The carbon tax rate of R120.00 per tCO_2-eq (tonne carbon dioxide equivalents) that the South African government initially proposed to be implemented in January 2015 was used to express these emissions in monetary terms. The proposed increase in the tax rate at 10% per annum until the end of 2019 was ignored, as no carbon tax rate has even been implemented to date.

Pienaar (1981) found a rectilinear correlation between fuel consumption, travel time and number of stops and stopped-time delays. This correlation is shown as a function of travel speed in ***Equation 4.8***.

$$F = K_C + \frac{K_D}{V} + K_E V + K_F V^2 \text{ ; } V \leq \text{optimum travel time per km} \qquad (4.8)$$

where

F	= urban vehicle fuel consumption in ml/km (or l/1000 km)
K_A and K_B	= constants (see ***Table 4.14***)
T	= travel time in s/km

The values in ***Table 4.14*** represent mean values based on fuel consumption in both directions so that the influence of gradients is negligible.

Table 4.14: Relationship between vehicle fuel consumption and travel time in South African cities.

Vehicle Class*	Constants				Optimum Travel Time (s/km)
	K_C	K_A	K_A	K_B	
Light motor vehicles	100	1467.6	-1.701	0.01524	57

* The fuel consumption rates shown here apply to vehicles with 50% utilisation of carrying capacity.

Once the fuel consumption had been evaluated (using the mean system speed per alternative and scenario), the CO_2 emissions were calculated per litre of fuel by multiplying the carbon content of the fuel with the ratio of molecular weight CO_2 (44) to the molecular weight Carbon (12), which is 3.7. For diesel and petrol, respectively, the carbon contents were taken to be 86% and 87%, and their densities 0.832 kg/l and 0.745 kg/l. Finally, the per-litre values were multiplied by the fuel consumption.

4.7.7 HEALTH BENEFITS: QUANTITATIVE AND QUALITATIVE

From the literature review (see ***Section 2.4.1.6.5)***, it is evident that the health-cost savings associated with an increase in physical activity are evaluated differently from country to country, and that a wide range of standard annual cost savings per cyclist was used in economic evaluations. Besides the issue of deciding which value of the wide range to use, using international standards and applying them to the South-African context poses questions about the transferability of the data. The economic value of a South-African life is much lower than the value of a statistical life in western European countries, for example. In addition, another significant challenge is understanding the dose-response relationship between physical activity, in this case cycling, and health benefits. The likely reduction in health risks varies per user, and is dependent on how the mode shift changes the total amount of physical exercise done by each of the potential users per day; the health benefits are much greater for previously inactive individuals compared to individuals who are already active for two hours a day, for example. In the travel surveys, participants were unfortunately not questioned about their present habits regarding physical exercise. For all these reasons, no standard value of a health-cost saving was applied for the bicycle-sharing alternative in this research project. But, since it is known that benefits do exist, some methodology had to be employed in the CBA; a qualitative analysis alone would not have represented the benefits well enough.

The World Health Organisation's Health Economic Assessment Tool (HEAT) has become the standard method for the UK government for incorporating physical activity benefits into transport appraisals (Pucher and Buehler, 2012). HEAT for cycling estimates the maximum and average annual benefit (per cyclist, per trip, and total annual benefit) due to the reduced mortality as a result of regular cycling. It uses population-level mortality data to estimate the number of adults that are expected to die in any given year in the target population and then calculates the reduction in expected deaths in this population (if a portion was to take up cycling) using the adjusted relative risk. The analysis is done online, where each required input is described in detail in every step. It was decided that the health benefits of the bicycle-sharing scheme for Stellenbosch would be calculated using this tool. The following inputs were required:

1. cycling duration, i.e. average time cycled per person = (avg. trip distance divided by average cycling speed)
2. number of cyclists = potential users
3. average age of the cyclists
4. national mortality rate
5. value of a VSL (see ***Section 4.5.2.5.6)***
6. time period over which benefits are calculated = service life
7. discount rate

A mortality rate instead of a morbidity rate is used, because the research on morbidity rates is still limited, and using these rates would thus lead to a greater uncertainty of the findings. The average European mortality rate of 159.04 deaths per 100,000 persons per year was applied to the results, because it was assumed that the potential-user population of bicycle-sharing more closely resembles the average European population than it does the average South African population. The main cause of death in South Africa at 22.6% is *certain infectious and parasitic diseases* (Statistics South Africa, 2013). These diseases include malaria and tuberculosis - illnesses that are less common in the higher-income groups.

A few assumptions are made in the methodology. These include that there is a linear relationship between the risk of death and cycling duration, that men and women have approximately the same level of relative-risk reduction, and that the average level of physical level of the studied population is similar to that of the general population.

It is important to note that HEAT is actually designed for adult populations, and that the user guide warns of applying the tool to populations of children, very young adults or older people. For this reason, the health benefits were evaluated only for the SU potential users.

Qualitative health benefits were also evaluated from the findings given in the literature review.

4.7.8 OTHER QUALITATIVE BENEFITS

There are other potential benefits for the theoretical bicycle-sharing scheme for Stellenbosch that have not yet been discussed in this section. These benefits include the improvement in safety and security to existing NMT users, job creation and economic stimulus, psychological benefits, a decrease in demand for parking and improved liveability. These are all qualitative benefits, however, that can only be evaluated with words. The benefits were evaluated based on a comprehensive literature review and applying the findings to the local context. These benefits are eluded to in ***Chapter 9***, but the full analysis of these benefits fell outside the scope of this research project.

4.7.9 EXTRAPOLATION OF THE BENEFITS

As stated in the introduction to ***Section 4.7***, the methodologies for evaluating benefits described thus far only calculated benefits for the AM-peak hour. The theoretical bicycle-sharing scheme, which can also be considered as a capacity enhancement project, is to be built mainly for AM peak traffic relief, but it will also generate benefits at other times of the day, especially the PM-peak period, and hence the step of extrapolating these results first to daily and then to annual benefits needed to follow. The User and Non-User Benefit Analysis for Highways manual (AASHTO, 2010) describes methods to do so. It refers to the extrapolation from a particular travel hour within the day to other travel hours of a day as the *diurnal travel measurement*, and the extrapolation from a particular year of analysis to later years of the project life as the *annual travel measurement.* To clarify, it was intended to exploit one detailed analysis of the project benefits for each alternative and each scenario for the AM-peak hour, and the results of these analyses were then to be extrapolated to daily, annual and service-life benefits using a formulaic extrapolation procedure.

Although a stable mathematical relationship between traffic volumes and benefits in both the null and the project alternatives exists, presented by the VD function, this is only the case for the links, not the nodes (the intersections: two-way stops, roundabout and signalised intersections).

It was then decided to evaluate the AM-peak benefits every 5 years applying the VD relationship only for the delays on the links, and use the formulated ICA report sheets to determine the node-delays by applying the traffic growth factor to all the turn movements. The VHT output-values were then to be added.

Equation 4.9 shows the equation applied for computing the link-delays for all alternatives other than the base and null alternatives. (The extrapolation procedure for the null alternative was described in ***Section 4.5.1***). The formula is only applicable to VD relationships that are of the BPR form.

$$\frac{VHT_m}{VHT_h} \cong \left(\frac{V_m}{V_h}\right)^{b+1} \tag{4.9}$$

where

VHT_m and VHT_h	=	total VHT for all the network links for scenarios / alternatives h and m, respectively
V_m and V_h	=	AM-peak volumes (veh/h) for scenarios / alternatives h and m, respectively
b	=	user-defined parameter from the BPR function

Taking *h* to be the null alternative, VHT_m was then the unknown.

Two different forms of the BPR function were applied in the Visum model to account for different VD relationships on different road classes. A b-value of 8 was ultimately used for road classes 1 and 2, and 6 was used for road classes 3 to 5 (see ***Chapter 5***). For the extrapolation procedure *b* was equalled to 7.

According to AASHTO (2010) "the technique works best in cases in which most user benefits result from travel-time savings, or other savings that are proportional to such benefits". Since travel speed, the input to the VOC equation, is related to travel-time, the technique was appropriate to use for the estimation of VOC and total travel-time savings.

Once all the AM-peak benefits were defined, it was assumed that the PM-peak benefits equal to half of these, because a broader PM peak is assumed to be observed due to combined work and shopping return trips, but mainly because the schools end in the middle of the day.

An issue that does arise with this type of extrapolation is how to deal with peak spreading. From the mathematical perspective, there is no limit to the traffic volumes and congestion levels that might be predicted for a link or intersection in a road network. In reality though, trip makers alter their times of travel when the delays on the network become too great. Without taking peak spreading behaviour into account, the results of benefit analyses may be an overestimation of the true benefits that will be realised with the improvement. The issue of peak spreading is addressed again ***Chapter 6.***

In conclusion, the extrapolation procedures discussed in this subsection were applied to all those benefits directly related to changes in the traffic volumes traversing the road network, i.e. benefits relating to VOC, travel time, CO_2 emissions and health. As already stated, the other total monetary benefits were calculated by making use of the CPI inflation rate. These benefits (per scenario and per user group, incl. the authorities) were then added to the total traffic-volume-related benefits to obtain the overall monetary project benefits of the alternative. The qualitative benefits, for which no extrapolation was needed, were given as an extra.

4.8 BICYCLE-SHARING REVENUE ASSESSMENT

The sources of potential revenue for the bicycle-sharing scheme were identified to be:

1. annual membership and access fees, and
2. advertising

The proposed annual membership and access fees were calculated from the present travelling expenses of the potential users, and the Matie bike subscription fee. These travelling expenses included VOC, student parking tariffs and the annual membership fee of the Somerset West Bus Fund (for scholars).

Market research was undertaken to determine the potential advertising revenue the scheme is able to generate.

4.9 BICYCLE-SHARING CASH FLOW ANALYSIS

4.9.1 ECONOMIC ANALYSIS VS. FINANCIAL ANALYSIS

There are two different approaches to estimating the net-benefits of a project investment. An economic evaluation assesses public profitability, whilst a financial analysis evaluates private profitability. An economic evaluation was hence undertaken to evaluate the profitability of the theoretical bicycle-sharing scheme to authorities, and a financial analysis determined the profitability of the scheme to the bicycle-share users, remaining road users and society as a whole. To convert a financial cost to an economic cost, a shadow price factor is applied to it. This factor is employed to exclude tax, profit and subsidy from market prices.

The VOC and VOT calculations are financial analyses. Hence, for the evaluation of the benefits to the individual road users and cyclists, the calculated values could be used, but for the general benefits to be reaped by the authorities, a shadow price factor had to be applied. A value of 0.8 was used for this factor. The construction costs of the Drop-and-Go zones and Park-and-Rides are also financial costs even though they exclude VAT. These costs were multiplied by a factor of 0.89 to take them to the economic costs. This is in line with the recommendations given by the *Guidelines for Conducting the Economic Evaluation of Urban Transport Projects* (Municipality of Cape Town, 1994). No shadow price factors were applied to the costs of the bicycle-sharing equipment.

4.9.2 SELECTION OF THE ECONOMIC EVALUATION TECHNIQUE

Off-the-shelf economic evaluation packages that aid in the CBA of road projects are available, but a manual calculation was preferred for this research project, as it was easier to account for all the different costs and benefits to the various trip makers and to the authorities. Additionally, the subject of bicycle-sharing deviates quite a lot from the typical road projects evaluated in practice.

The economic viability of the theoretical bicycle-sharing scheme for school and university destined commuter traffic in the town of Stellenbosch was determined using three economic evaluation techniques, each with its own performance measure. The techniques were:

1. Net Present Value (NPV)
2. Benefit / Cost Ratio (BCR)
3. First Year Rate of Return

4.9.2.1 NET-PRESENT-VALUE TECHNIQUE

In the NPV technique, the present worth of the investment costs (incl. maintenance and operational costs) is subtracted from the present worth of all the future project benefits. The present worth of the costs and benefits is calculated using the discount rate explained and defined in ***Section 4.5.2.5.1***. The formula for these present worth of costs (PWOC) and benefits (PWOB) are shown in ***Equations 4.10*** and ***4.11***, respectively. For the null alternative, the first term in ***Equations 4.10*** falls away, because the investment costs of the existing road network are taken as sunk costs. The formula is given as ***Equation 4.12***.

$$PWOC = \sum_{t=0}^{j} \frac{C_t}{(1+d)^t} + \sum_{t=k}^{n} \frac{(M+O+U)_t}{(1+d)^t} \tag{4.10}$$

where

PWOC	=	present worth of costs
t	=	evaluation period
d	=	risk-free discount rate
C_t	=	implementation costs incurred over the period t
$(MO + U)_t$	=	maintenance, operational and user costs incurred over period t

$$PWOB = \sum_{t=k}^{n} \frac{B_t}{(1+d)^t} \tag{4.11}$$

where

PWOB	=	present worth of benefits
B_t	=	benefits reaped over period t

$$\mathrm{NPV} = \sum_{t=k}^{n} \frac{B_t}{(1+d)^t} - \sum_{t=0}^{j} \frac{C_t}{(1+d)^t} + \frac{S_t}{(1+d)^t} \tag{4.12}$$

where

NPV	=	net present value of benefits
S_t	=	terminal salvage value of the project

All projects reflecting a positive NPV are economically viable; the project alternative with the highest value is the most so.

4.9.2.2 BENEFIT / COST RATIO TECHNIQUE

In the BCR technique, the ratio between the PWOC and PWOB is determined. This ratio makes the economic viability of a proposed project immediately apparent to decision makers. The formula is given as ***Equation 4.14***. A ratio greater than 1 denotes economic viability; the project alternative with the highest ratio is economically the most advantageous. The economic viability of a project or alternative is seen as medium when the BCR lies between 1.5 and 2, and high when it is above 2.

$$\mathrm{BCR} = \sum_{t=k}^{n} \frac{B_t}{(1+d)^t} / [\sum_{t=0}^{j} \frac{C_t}{(1+d)^t} + \sum_{t=k}^{n} \frac{(M+O+U)_t}{(1+d)^t} - \frac{S_t}{(1+d)^t}] \tag{4.13}$$

4.9.2.3 FIRST-YEAR-RATE-OF-RETURN TECHNIQUE

The FYRR technique is the same as the BCR technique, except that only the first-year benefits are evaluated over the total project costs.

4.10 BICYCLE-SHARING SENSITIVITY ANALYSIS

The bicycle-sharing sensitivity analysis has been mentioned a few times in this section. A sensitivity analysis is a way of formally recognising the uncertainty of key factors used in an analysis, such as a CBA, and experimenting with alternative values in the re-calculation of costs and benefits. When a future projection is made with values that comprise a degree of uncertainty, this uncertainty becomes even greater, and hence it is important for sensitivity analyses to be performed. In general though, if a project is found to be feasible (or infeasible) irrespective of the exact value used for some of the variables, then the analysist can be more confident about his / her methodology and assumptions.

The sensitivity analysis described here is different to the scenario analysis portrayed in ***Section 4.5.2.2*** in that the sensitivity analysis is carried out to test the sensitivity of the project findings to changes in the value of those parameters for which there was uncertainty, and the scenario analysis more has to do with the effect different designs have on the outcome. Because a great number of scenarios were already being tested, the bicycle-sharing sensitivity analysis looked only at the effects of the following variables:

1. VOT – VOT = 0.25 × hourly wage (instead of 0.5); and
2. vehicle occupancy – using 1.2 passengers per vehicle instead of 1.5.

They both relate to the travel-time cost.

5 RESULTS: PREVAILING TRAFFIC CONDITIONS AND MODEL CALIBRATION

This chapter is the first of a few that in succession discusses the results that go hand-in-hand with the methodology described in ***Chapter 4***. In this section specifically, the prevailing traffic / travel conditions of the study area are revealed, which includes defining the time period related to the AM-peak hour. No costs are calculated yet, because it is the null alternative, not the prevailing conditions, against which the costs of the bicycle-sharing scheme were evaluated. The order in which the subsections are presented here is identical to how the methodology was relayed in ***Section 4.4***.

5.1 RESULTS: TRAFFIC VOLUME STUDY

As stated in ***Section 4.4.1***, the morning peak hour was defined from the highest total of four consecutive 15min-volumes between 06:45 and 08:15 for the southern approach of the R44 / Van Reede intersection. ***Table 5.1*** shows the total observed 15-min volumes for all movements of this approach. It can be seen that, at least based on traffic counts, the 07:00 to 08:00 time period is the peak hour for the approach, with a total inflow of 2,072 vehicles. In 2013, the peak hour was observed for the same time period. The total traffic volume for this hour is, however, only marginally greater than that for the 06:45 to 07:45 period (2067 vehicles). The videos show though that whilst lower traffic volumes were observed for the through-movements of the 07:30-to-07:45 and 07:45-to-08:00 15-min intervals, this was not due to a reduced demand; downstream bottlenecks and congestion prevented efficient throughput at the approach.

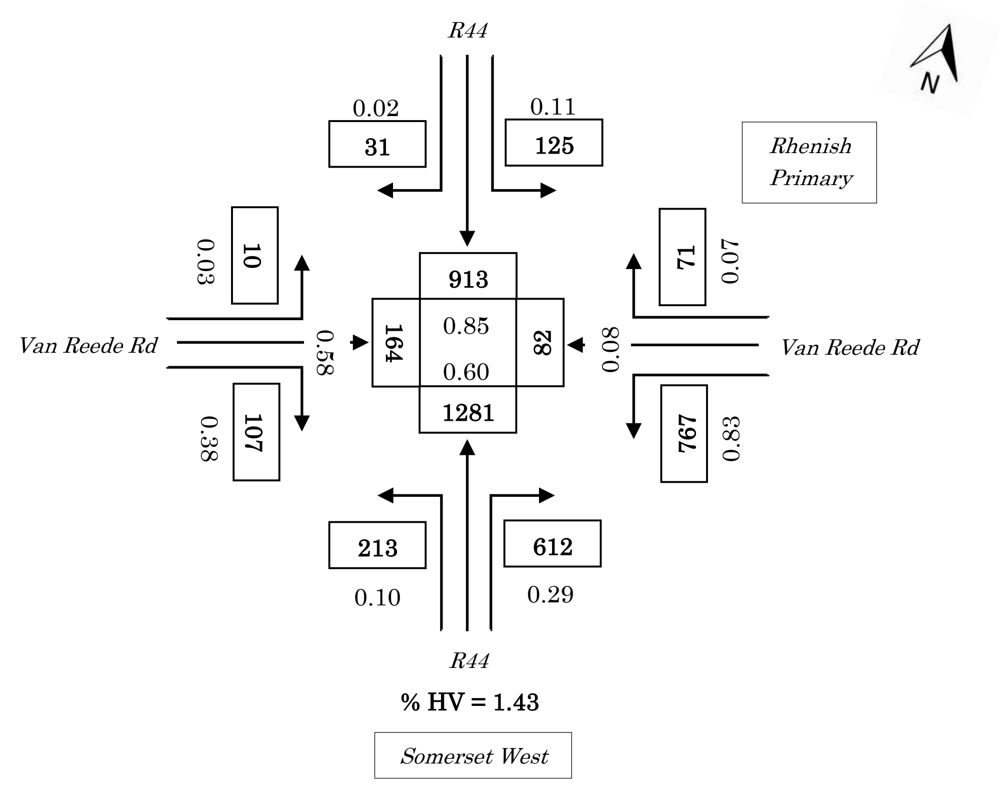
Table 5.1: 15-min traffic volumes counted between 06:45 and 08:15 at the southern approach of the R44 / Van Reede intersection on 13 August 2015.

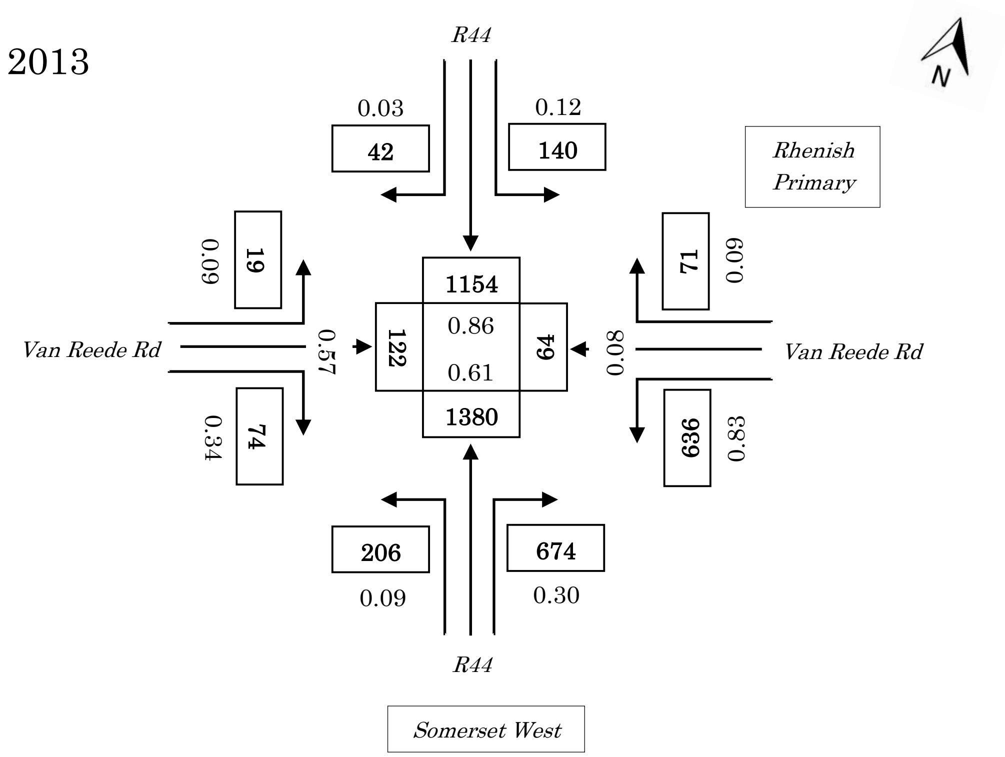
Time period		15-min volume
06:45 to 07:00	06:45-07:45	452
07:00 to 07:15	07:00-08:00	590
07:15 to 07:30	07:15-08:15	544
07:30 to 07:45		481
07:45 to 08:00		457
08:00 to 08:15		420

The adjusted (i.e. based on the volumes counted on 13 August 2015) AM-peak-hour volumes for every movement at each of the intersections in the study area are shown in ***Appendix E.2***, ***Table E.1***, together with the turn proportions. The volumes are totals of the four 15-min intervals between 07:00 and 08:00. The numbering system applied to the intersections is depicted in ***Appendix E.1***, ***Figure E.1***. It falls within Area 2 shown on the map in ***Figure A.1***. In the case where an intersection number has an *a* and a *b* part, the former relates to the 2015 counted volumes and the latter to the volumes counted by the Stellenbosch Municipality in 2013. The PHFs for the major intersections are also given in ***Table E.1;*** the input to the PHF calculations is provided in ***Appendix E.3***, ***Table E.2***. ***Table 5.2,*** *however*, is an extract of ***Table E.1*** for the three major signalised intersections on the R44, namely intersection 2, 4 and 5 (R44 / Van Reede, R44 / Saffraan, and R44 / Dorp, respectively).

Table 5.2: The adjusted 2015 and 2013 AM peak-hour volumes, turn proportions and PHF for the major signalised intersections in the study area.

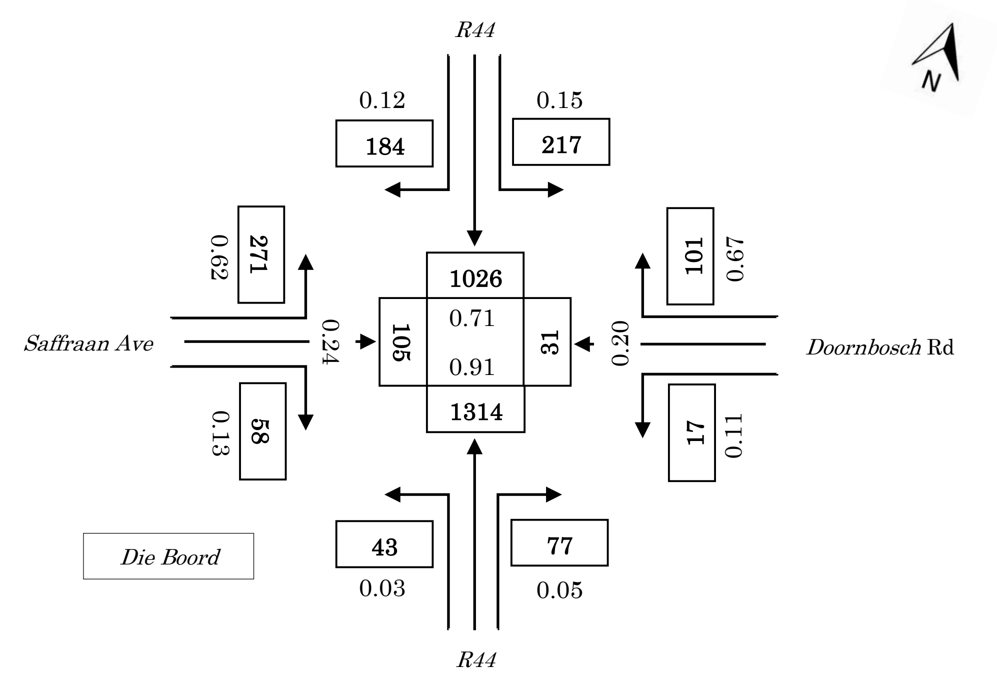
<table>
<tr><td>2a

(PHF = 0.97)</td><td>
</td></tr>
<tr><td>2b

(PHF = 0.96)</td><td>
</td></tr>
</table>

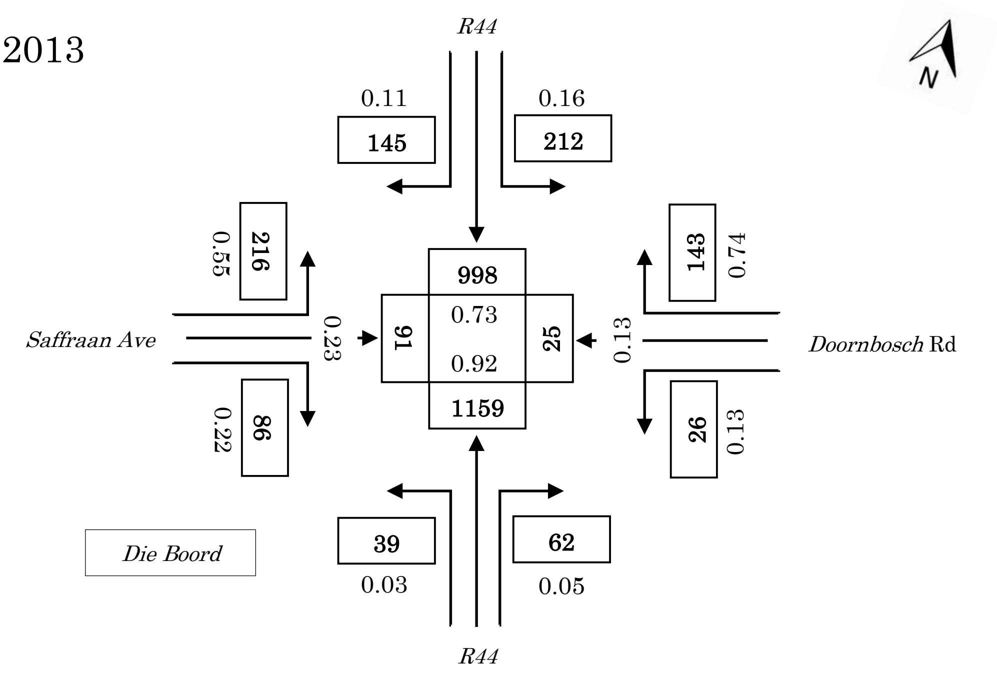
4a

(PHF = 0.88)



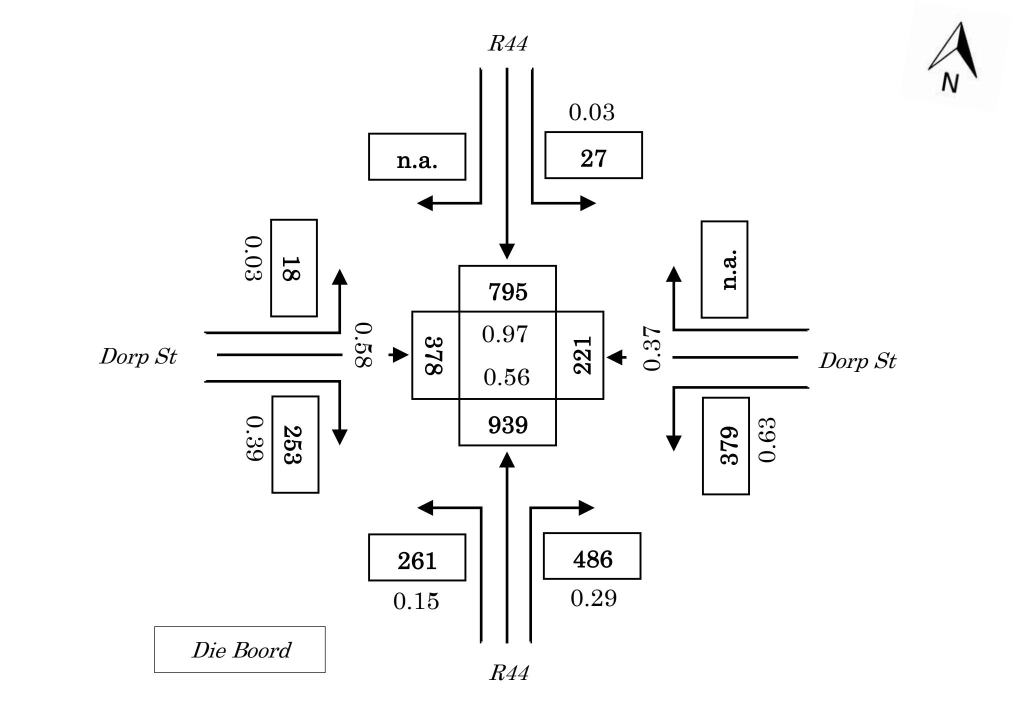
4b

(PHF = 0.85)



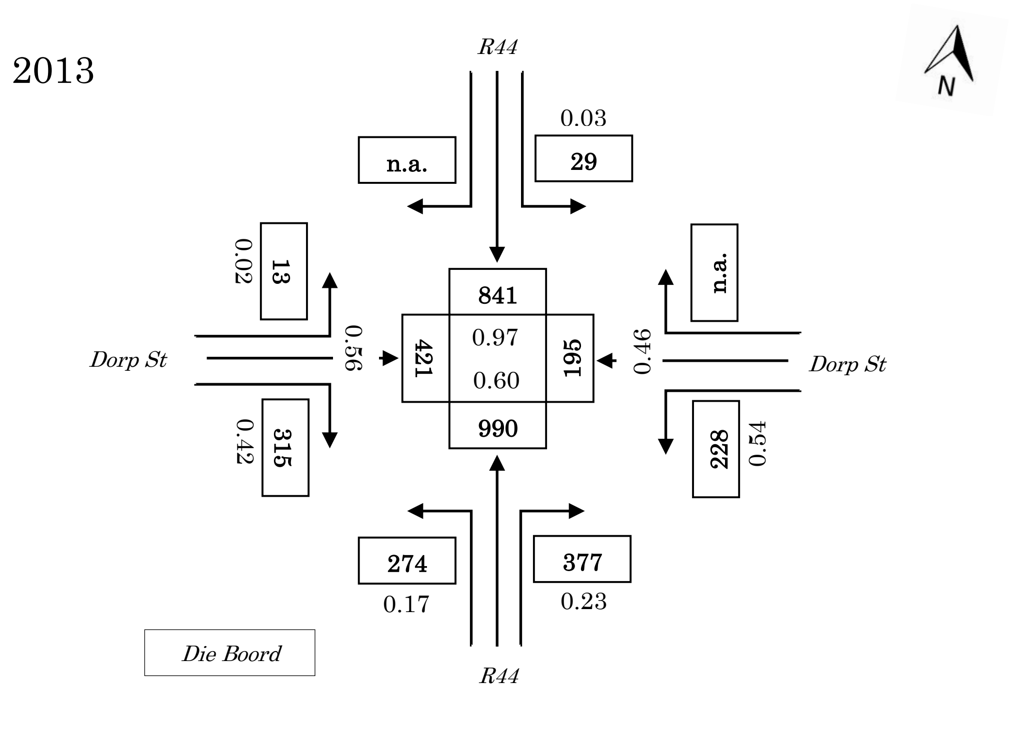
5a

(PHF = 0.96)



5b

(PHF = 0.88)
(for 07:15 to 08:15)



For the southern approach of the R44 / Van Reede intersection, heavy vehicles were counted separately from light motor vehicles during the AM peak hour. 8 buses were counted, 5 large goods vehicles and 16 light commercial vehicles, resulting in a heavy vehicle (HV) proportion of 1.4%. This low proportion, and taking into consideration that it comprises mainly of light commercial vehicles, led to the fact that all counted vehicles were taken to be light motor vehicles in this research project; no PCE factors were applied.

No clear pattern of traffic growth could be observed when comparing the 2015 and 2013 traffic volumes at intersections 2, 4 and 5 (R44 / Van Reede, R44 / Saffraan, and R44 / Dorp, respectively). The data, in fact, shows a decrease in total traffic of 1.88% at intersection 2. Because of the severe congestion that was witnessed on the videos at this intersection, the student suspects that the decrease is explained by the increase in traffic downstream (1.0% and 3.73% found at intersections 4 and 5, respectively). The decrease may, however, also be attributable to the fact that the results of two one-day studies were being compared; some external factors could have been at play at the time the volume counts were conducted. This is where probe data came into play; probe data was used to analyse the change in travel time and speed at the intersections over the two years to help evaluate the pattern in traffic growth.

The adjusted traffic volumes given in ***Table E-2*** served as the input to the Visum model.

5.2 RESULTS: PROBE DATA

5.2.1 TRAVEL TIME AND TRAVEL SPEEDS RESULTS: AM PEAK HOUR

Using probe data, the AM peak hour was determined from the same three potential AM peak hours as for the traffic volume counts, namely 06:45 to 07:45, 07:00 to 08:00 and 07:15 to 08:15. Speed profiles and cumulative-travel-time graphs were drawn for the R44 corridor for these three potential AM peak hours, as well as for free-flow travel conditions, to establish the actual AM peak hour. The graphs, given as ***Figure 5.1 and 5.2,*** show a clear pattern of travel speeds and cumulative travel times along the entire R44 corridor (Annandale Rd to Van Reede Rd). The input data, retrieved from the probe data queries described in ***Section 4.4.2,*** are shown in ***Appendix E.4***, ***Table E.3*** (for speed profiles) and ***Table E.4*** (for cumulative travel time graphs).

At a first glance, it is clear from both figures that average travel speeds are a lot higher and cumulative travel times a lot lower during free flow than during the AM peak hours. The two graphs show, as for the traffic-volume analysis, that the traffic conditions for the 07:15-to-08:15 period are overall always slightly better than for the other two AM periods. The difference in traffic conditions between the 06:45-to-07:45 and 07:00-to-08:00 time periods is marginal again, however. The peaks in the speed profiles indicate the effect signalised control at intersections has on traffic flow. A drop in the average travel speed is observed just before the signalised intersection and an increase in average travel speed is observed again just after the intersection. The 07:00-to-08:00 time period has the lowest average travel speed at the end, and in general is the line that is at the bottom most (i.e. lowest speed). The assumed reason why the 07:15-to-08:15 period has the lowest average speed before Technopark is that office hours begin slightly later than the time of the first bell at the schools, and since Technopark is closer to Somerset West than the centre of Stellenbosch, travellers with a destination in Technopark can leave home a little later than other commuters. The peak travel time period at Technopark, therefore, lies more closely around 08:00. The gap between the 06:45-to-07:45 and 07:00-to-08:00 line in ***Figure 5.3*** is very small to almost non-existent at some points. The total cumulative travel time is slightly higher for the 07:00-to-08:00 period though. For the free-flow period, the gradient of the cumulative travel time graph is constant, which means that no, or at least very little, delay is encountered along the route during this time. For the AM periods, the gradients are not only a lot steeper (a sign of increased average travel times), but they also vary along the route. It is very

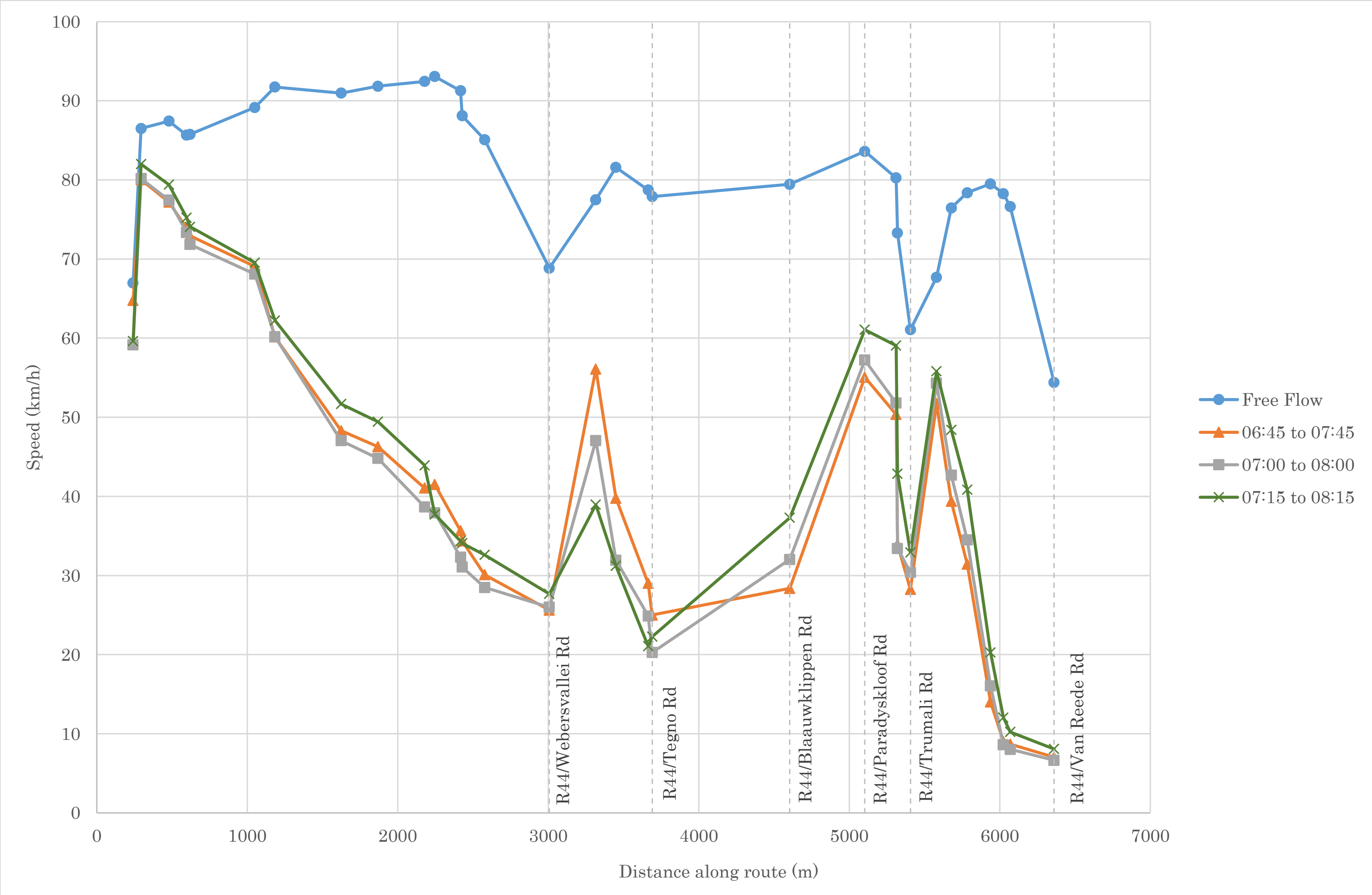


Figure 5.1: Speed profiles of the studied corridor for the three potential AM peak hours and free flow.

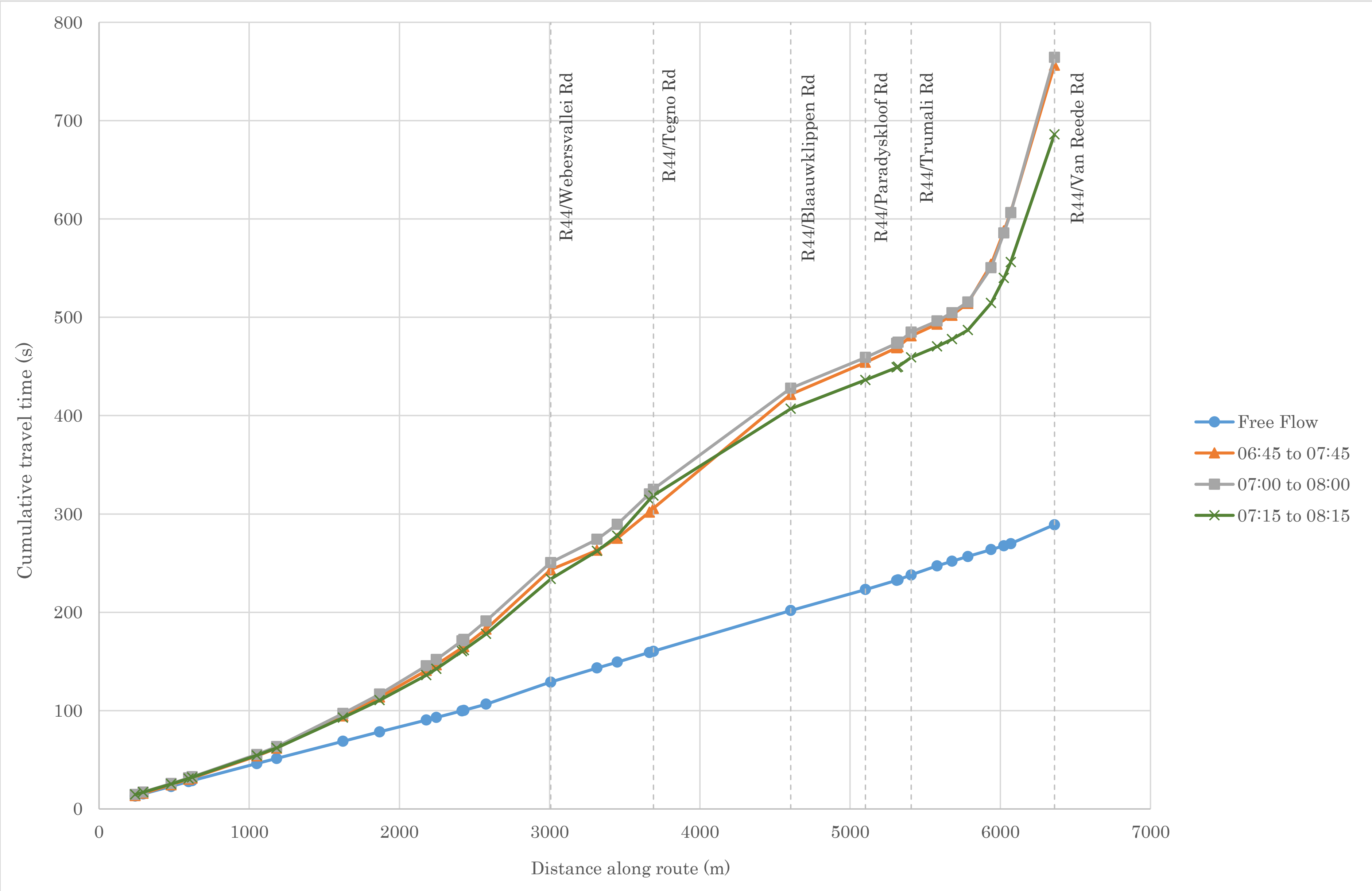


Figure 5.2: Cumulative travel time graphs for the studied corridor for the three potential AM peak hours and free flow.

important to note the extremely steep gradient for the approximately last 600m of the corridor. Here, the average travel time is increasing at a much faster rate than the distance, which results in vast travel time delays.

All in all, the 07:00-to-08:00 time period was defined as the peak period. Whilst the traffic conditions are very similar in the 06:45-to-07:45 and 07:00-to-08:00 time periods, the ultimate goal is to reduce traffic congestion in the town itself, so a 06:45-to-07:45 peak hour far back on the corridor is going to result in a 07:00-to-08:00 peak hour in town anyhow.

5.2.2 TRAVEL TIME AND TRAVEL SPEED RESULTS: ALT. ROUTES

The results of the 2015 AM-peak-hour probe data query for the four routes defined in ***Section 4.4.2*** are shown in ***Table 5.3***. To repeat, the routes were defined as follows:

Route 1 = R44 Corridor (Annandale Rd to Van Reede Rd)
Route 2 = R44 / Van Reede to Dorp / Piet Retief via Dorp
Route 3 = R44 / Van Reede to Dorp / Piet Retief via Van Reede / Koch
Route 4 = R44 / Van Reede to Dorp / Piet Retief via Van Reede / Vrede

Table 5.3: 2015 probe data analysis output for the R44 corridor and the three main routes between the R44 / Van Reede intersection and the intersection of Dorp St and Piet Retief St.

Parameters	Road section	Route 1		Route 2	Route 3	Route 4
		Free-flow	AM peak	AM peak	AM peak	AM peak
average travel speed (km/h)	entire route	79.22	29.96	11.5	18.25	13.81
	per segment	see *probe data provided on attached CD*				
15th percentile travel speed (km/h)	entire route			7.72	12.06	7.65
85th percentile travel speed (km/h)	entire route			20.34	27.80	26.40
cumulative travel time (min)	entire route	4.82	12.74	8.62	5.46	6.27
travel time (min)	per segment	see *probe data provided on attached CD*				
average travel time delay (min)	entire route	7.92				
15th percentile travel time (min)	entire route			4.87	3.58	3.27
85th percentile travel time (min)	entire route			12.83	8.27	11.32
travel time ratio	per segment	see *probe data provided on attached CD*				

For route 1, not too much time was spent on evaluating the parameters for the entire route, because it was the details, i.e. analysis per segment, that were important for determining the location of the Drop-and-Go zones and the Park-and-Rides. The average travel speed and the average cumulative travel time for the entire corridor were given though, so that at least some of the results for the individual segments could be compared not only to each other, but also to the average results of the entire route. An average travel time delay of 7.92 min during the AM peak hour may not seem like that much at all, but it must be remembered that all travel time delay encountered beyond the arterial, i.e. in town, must still be added to this delay. The complete set of results, i.e. per segment results, is included on the attached CD, and the per-segment analysis is done in ***Chapter 9***, where the bicycle-sharing scheme for Stellenbosch is proposed.

The average cumulative travel time (and related average travel speed) of 8.62, 5.46 and 6.27 min for each of the three alternative routes (routes 1 to 3, respectively) between the R44 / Van Reede intersection and the intersection of Dorp St and Piet Retief St, will be compared to findings of the Visum base model. The reason that the AM-peak-hour results for these routes are not compared to free flow, is because the free-flow data is incomplete: no data was available for some of the segments and very low average sample sizes were found for the rest (<10).

5.3 PTV VISUM 15 MODEL

5.3.1 THE NETWORK

All network statistics of the Visum model, i.e. the total number of each network object in the network, were already given in ***Section 4.4.3.1***, and the locations of the 18 zones were given in ***Section 4.4.3.2***. ***Figure 5.3*** is another illustration of the network, indicating:

1. the positions and numbers of the nodes,
2. the positions and numbers of the main nodes (shown in red), and
3. the names of the links, i.e. street names.

These are referred to in various tables of the Appendices.

Other network details can be found in the base-model Visum *ver.* file on the attached CD.

5.3.2 THE O-D MATRIX

Table 5.4 shows the balanced original matrix as introduced and defined in ***Section 4.4.3.2***. The 25x25 matrix of trip-production proportions per zone *i* to all the other zones *j* and the associated original matrix of vehicle trips (without subzones) are given in ***Appendix E.5***, ***Tables E.5*** and ***E.6***, respectively.

5.3.3 RESULTS: ASSIGNMENT, CALIBRATION AND GOODNESS-OF-FIT

The results of the equilibrium assignment, in terms of the modelled volumes per link, are shown in comparison to the observed volumes (from the traffic counts) in ***Figures 5.4*** and ***5.5*** for the Krigeville study area and R44 corridor, respectively. The modelled volumes are given closest to the link in the colour red; the observed volumes are displayed in green, further away from the link. The result of the TFlowFuzzy procedure, i.e. a corrected O-D matrix, is shown as ***Table 5.5***.

Except to zone 8, which has multiple connectors, all O-D pairs were assigned to only one path, i.e. there are no alternative routes for the trips belonging to an O-D pair. This was believed to be acceptable taking into account the relatively simplistic network that was modelled. Moreover, it was stated in ***Section 4.4.1.3.3*** that with stochastic assignment more routes are loaded, but also that this assignment procedure did not represent reality as well as the combination of equilibrium assignment and demand matrix calibration that was finally used. The paths per O-D pair for the Visum base model are listed in ***Appendix E.6***, ***Table E.7*** in terms of street names.

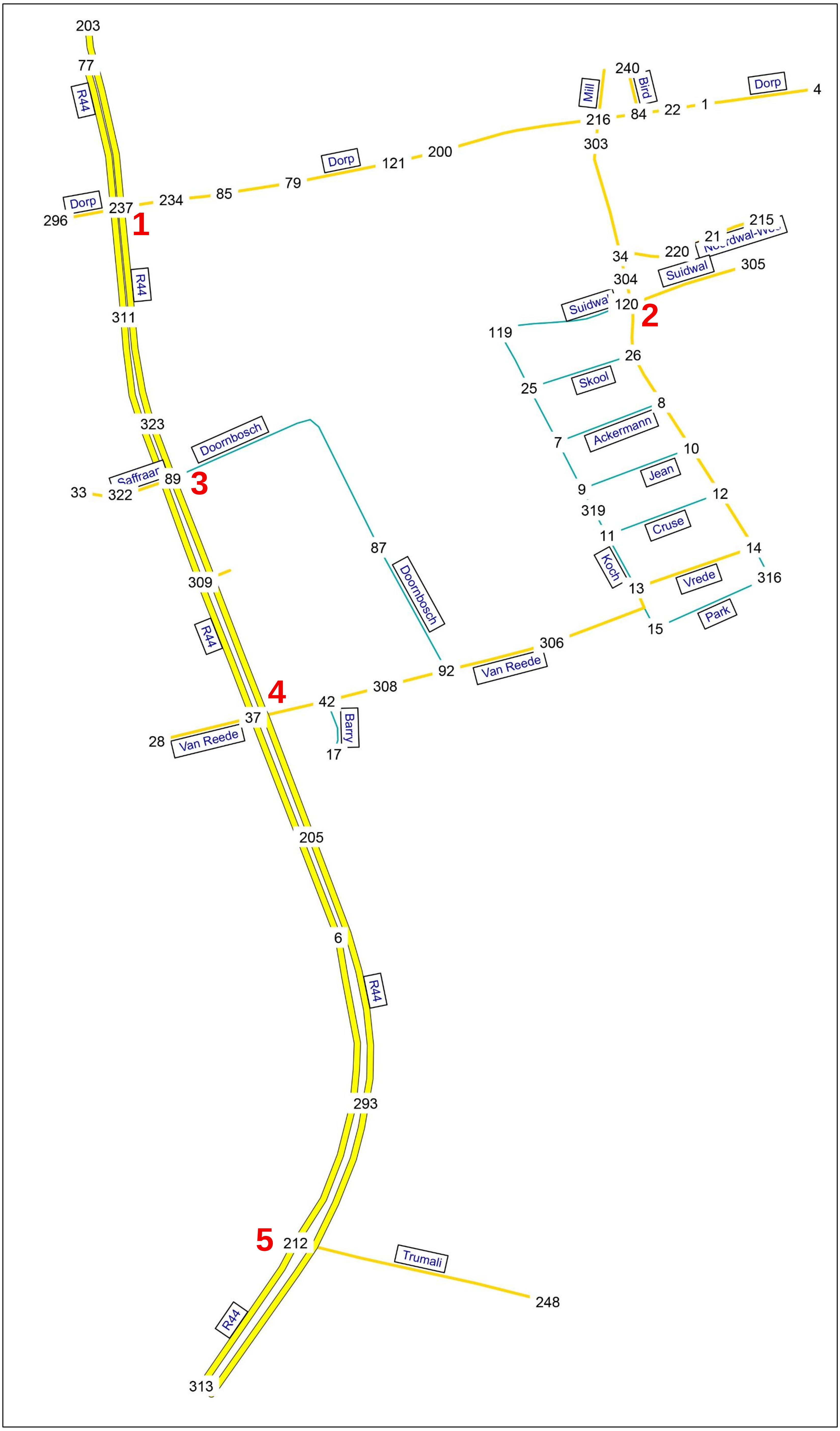


Figure 5.3: An illustration of the network showing node numbers, node positions and street names.

Table 5.4: The balanced original O-D matrix.

BALANCED ORIGINAL O / D MATRIX 7-8AM		DESTINATIONS																		
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	
		ATTRACTIONS																		
		1673	324	39	256	764	478	948	242	674	392	62	285	347	360	783	173	68	261	**8129**
ORIGINS	**PRODUCTIONS**																			
1	2182	27	211	32	37	210	177	629	88	144	96	5	36	42	2	272	16	39	119	2182
2	281	98	0	0	0	39	3	5	1	7	1	0	5	11	1	88	3	10	9	281
3	38	18	1	0	0	1	2	8	3	1	1	0	0	0	0	1	0	0	2	38
4	434	42	2	0	0	98	22	186	23	25	23	1	1	1	0	4	1	1	4	434
5	556	151	16	1	33	0	15	69	8	37	10	1	24	22	1	146	6	3	13	556
6	649	148	6	1	33	48	0	21	105	123	114	6	2	5	2	16	6	1	13	649
7	822	439	16	2	107	141	3	0	9	14	9	0	4	5	1	27	2	4	39	822
8	6	2	0	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	6
9	538	129	9	1	19	42	100	2	0	17	103	26	2	16	6	33	21	1	11	538
10	375	111	7	1	16	36	84	2	0	15	0	22	2	14	5	32	18	1	10	375
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	253	77	8	0	0	27	1	0	0	13	1	0	0	23	11	50	31	2	8	253
13	367	106	12	0	1	36	17	0	0	27	2	0	21	0	12	78	44	2	9	367
14	336	22	1	0	4	12	16	0	0	98	12	1	77	90	0	0	3	0	0	336
15	763	132	13	0	1	42	20	8	1	71	10	0	56	61	315	0	21	2	10	763
16	286	37	4	0	3	16	11	1	0	76	6	0	54	54	4	16	0	1	3	286
17	188	117	14	0	0	11	2	6	1	4	1	0	2	2	0	16	1	0	11	188
18	55	17	4	1	1	4	3	11	3	3	2	0	0	1	0	4	0	1	0	55
	8129	1673	324	39	256	764	478	948	242	674	392	62	285	347	360	783	173	68	261	

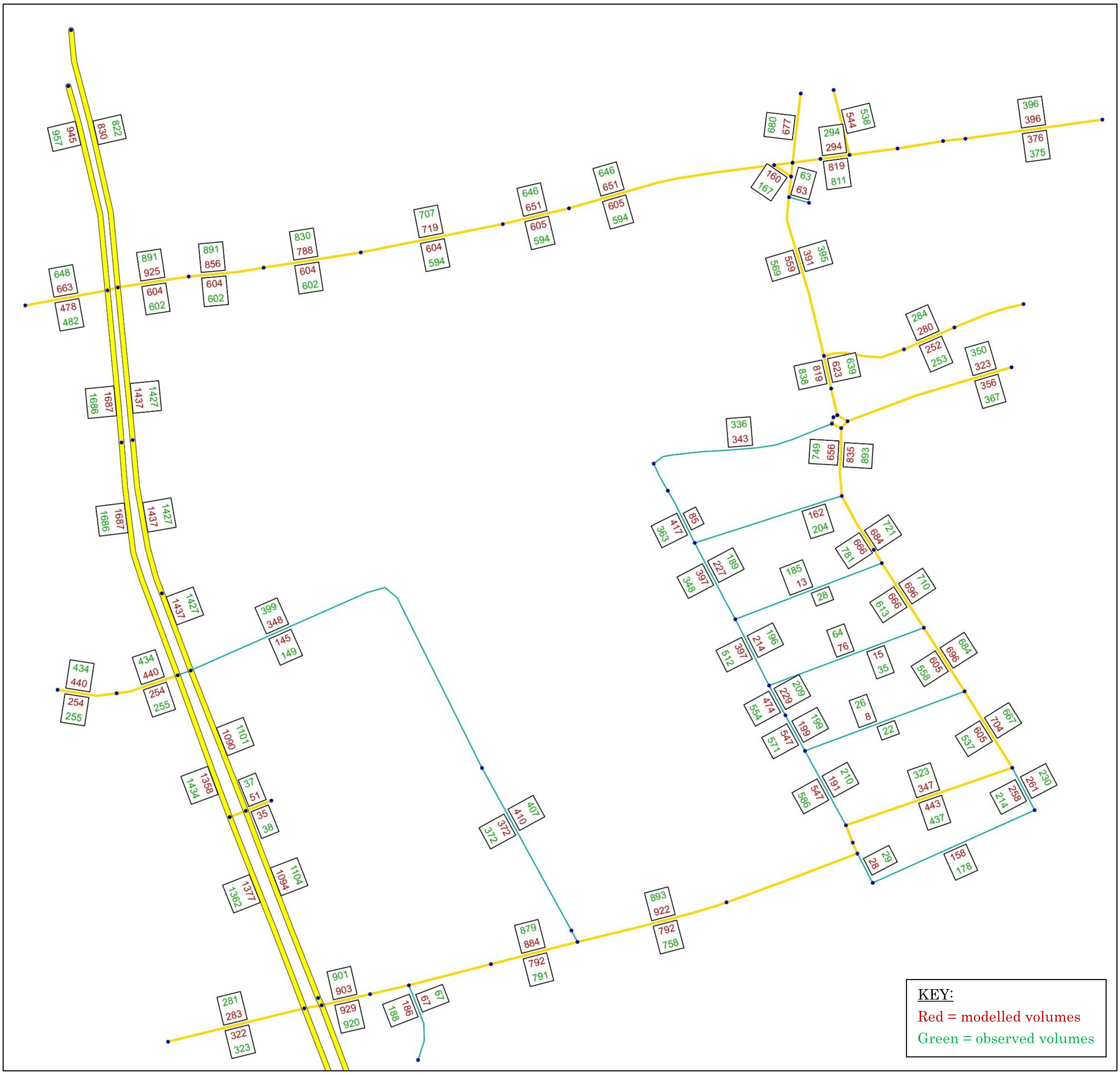


Figure 5.4: Modelled volumes after equilibrium assignment vs. observed volumes on every link in the Krigeville study area.

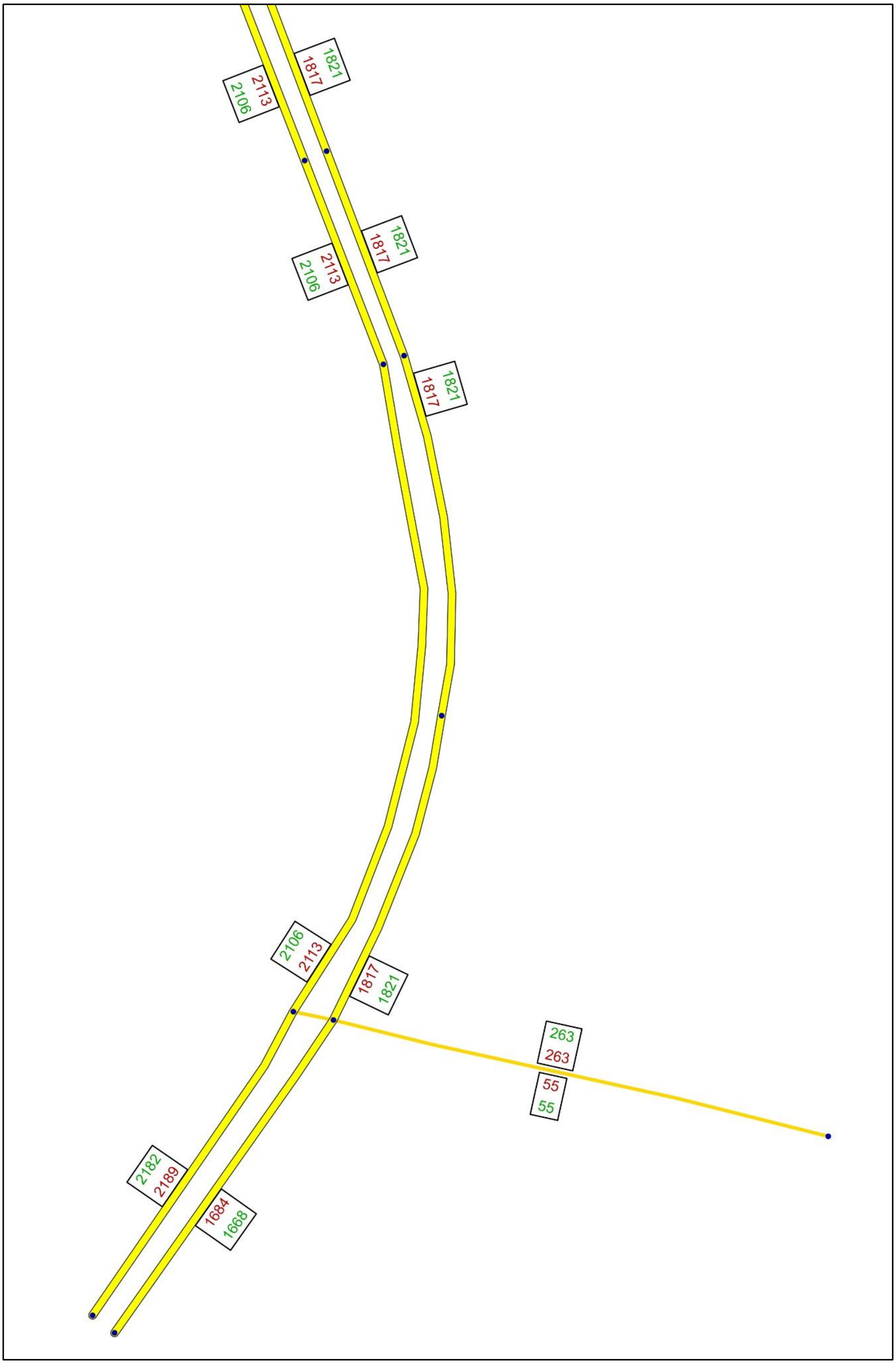


Figure 5.5: Modelled volumes after equilibrium assignment vs. observed volumes on every link on part of the R44 corridor.

Table 5.5: The corrected O-D matrix after execution of the TFlowFuzzy Procedure.

CORRECTED O-D MATRIX 7-8AM		DESTINATIONS																		
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	
		ATTRACTIONS																		
		1673	324	39	256	764	478	948	242	674	392	62	285	347	360	783	173	68	261	**8129**
ORIGINS 1	PRODUCTIONS 2182	27	205	45	21	155	204	657	118	139	75	8	100	74	4	257	12	4	113	2216
2	281	97	0	0	0	32	2	2	1	5	0	0	15	21	2	92	2	1	9	283
3	38	2	0	0	0	14	1	5	2	0	1	0	0	0	0	10	0	0	0	35
4	434	5	0	0	0	114	22	167	26	17	30	1	1	3	0	43	9	1	1	440
5	556	136	16	6	33	0	11	44	7	31	13	1	65	38	2	135	4	1	12	554
6	649	157	5	0	33	33	0	18	109	74	135	8	1	11	2	16	36	9	14	663
7	822	483	15	0	111	101	9	0	5	4	5	0	1	6	0	2	6	39	45	830
8	6	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	4
9	538	133	7	0	18	45	45	5	0	17	101	24	1	26	3	29	91	4	12	562
10	375	77	4	0	10	54	26	3	0	30	0	14	1	16	2	76	54	3	7	376
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	253	122	14	0	0	40	2	0	0	13	1	0	0	6	1	15	23	1	13	252
13	367	159	20	0	4	51	35	0	0	26	2	0	7	0	1	4	30	1	14	356
14	336	35	2	0	10	18	51	0	0	146	14	7	41	91	0	0	13	0	0	428
15	763	71	8	0	1	21	20	13	5	32	4	0	9	6	397	0	8	0	6	600
16	286	86	10	0	11	35	42	7	0	134	8	0	34	22	2	15	0	1	7	416
17	188	102	13	0	0	4	6	15	3	16	3	0	3	2	0	8	0	0	10	186
18	55	18	3	1	0	2	3	9	3	8	3	0	0	1	0	3	0	0	0	55
	8129	1712	322	51	254	720	478	945	279	694	396	62	280	323	417	705	289	67	263	

The number of iterations specified for the assignment procedure was reached without attaining a balanced network. The GEH and R^2 test results indicate, however, that the modelled volumes fall within the boundaries of the acceptable error. For the turns and main turns, 7.62% of all the modelled volumes have a GEH value above 5; this is only just over half of the percentage allowed, namely 15%. For the links, the percentage is as low as 3.93%. The individual GEH for every turn and main turn, as well as every link, is shown in ***Appendix E.7***, ***Tables E.8*** and ***E.9***, along with other base-model results. The R^2 value is 0.997 for both the turns / main turns and the links, indicating an almost perfect match.

5.3.4 RESULTS: DELAYS AT THE NODES

The delays that were calculated per turn movement at all of the nodes that represent intersections are given in ***Appendix E.8***, ***Table E.10***. The detailed ICA reports per intersection form part of the content on the attached CD. A summary of the control delay, level of service and back of the queue are also given in ***Appendix E.8***, ***Tables E.11 to E.16***, though, for the major intersections identified in ***Section 4.2***.

5.3.5 RESULTS: PERFORMANCE MEASUREMENT

5.3.5.1 VMT, VHT AND MEAN SYSTEM SPEED

After the delays at all of the nodes were re-entered in the model, the VMT and VHT were determined per O-D pair and for the entire network using skim matrices and the O-D matrix filled with vehicle trips per O-D pair. The mean system speed was then calculated from these results. ***Tables E.17 and E.18*** in ***Appendix E.9*** show the VMT and VHT matrices. The totals for the entire network are shown in the bottom right-hand corner of the tables. They are 13,156.62 km and 34,707.81 min, respectively, which results in a system mean speed of 22.74 km/h. ***Appendix E.9***, ***Table E.19*** shows the modelled travel speed for every O-D pair. The matrices of travel distance between each origin and destination, and the modelled travel times per O-D pair and per vehicle, i.e. not VHT, are included in ***Appendix E.9***, ***Tables E.20*** and ***E.21***, respectively.

5.3.5.2 MODEL CALIBRATION: VISUM RESULTS VS. PROBE DATA

The average travel times for the three studied alternative probe data routes were extracted from the model, and these were the results:

- Route 2 = 6.23 min (opposed to 8.62 min from probe data)
- Route 3 = 4.26 min (opposed to 5.46 min from probe data)
- Route 4 = 3.25 min (opposed to 6.27 min from probe data)

It is evident that the modelled travel times are all lower than those obtained from probe data. A change to the base model thus had to be made to match the modelled outputs more closely to the probe data outputs. Uncertain inputs to the model included the VD functions and the capacities of the individual road segments. Since the b parameter (with a value that typically ranges between 4 and 10) is an exponent in the VD function, which means a quick growth for a small change in its value, changing its value was the first attempt at improving the modelled results. The following adjustments were made:

1. $b = 8$ (opposed to 6), for road classes 1 and 2
2. $b = 6$ (opposed to 4), for road classes 3 to 5,

and the results were as follows:

- Route 2 = 6.40 min
- Route 3 = 5.80 min
- Route 4 = 4.11 min.

Neither realistic modifications to the *b* parameter nor to the capacity had any significant effect on the average travel time on the R44 that forms part of route 2. The arrival types at main nodes 1 (R44 / Dorp St) and 3 (R44 / Saffraan Ave) were then changed from arrival type 3 to arrival type 1 in the control-delay calculation, which when looking at the traffic volumes at each of their nearest upstream intersections is perhaps anyway the arrival-type choice that resembles reality best. This increased the average travel time for route 2 to 6.91 min. This value was accepted, since it is not known for definite that the probe data is accurate. The average sample size per segment of the route was 17.47, which compared to the total number of vehicles traversing the route within the hour is not high, and it is hence very likely that the probe vehicles travelled on the route during the short extreme peak traffic of the hour. An adjusted summary of the control delay, level of service and back of queue at main nodes 1 and 3 is presented in ***Appendix E.10***, ***Tables E.22*** and ***E.23***.

For route 3, the edited VD function altered the travel time to a value that is greater than that for the probe data, but only by 20 s. This value was accepted, and no further adjustments were made to the route.

The travel time for route 4 was still over 2 min below the probe-data value. The link type of the last road segment before main node 2 (Piet Retief / Suidwal roundabout) was changed to a residential road, i.e. the capacity was reduced from 800 veh/h to 400 veh/h, because there is a lot of pedestrian activity present just before the roundabout during the AM peak hour. This adjustment raised the average travel time of the entire route to 5.26 min. This value was accepted for the same reasons named for route 2.

Now that the Visum model was verified, it could be used to test the different scenarios of the bicycle-sharing alternative. The altered VHT matrix is given as ***Table 5.6***. The new mean system speed of 18.13 km/h is another confirmation of the congestion problem in the study area. The new average travel speeds per O-D pair are shown in ***Table 5.7***, and the new travel times per vehicle per O-D pair are given in ***Table 5.8***.

Table 5.6: Adjusted VHT (in min) per O-D pair for the base model.

VHT new		DESTINATIONS																	
7-8AM		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
ORIGINS	1	0.00	611.97	190.66	106.73	896.50	1401.15	4610.45	990.29	1285.07	710.05	75.03	1133.42	810.35	42.01	2071.34	83.90	22.10	434.35
	2	290.56	0.00	0.00	0.00	85.02	6.35	9.97	3.42	34.30	1.25	0.00	126.37	168.36	15.29	454.88	9.68	2.78	32.81
	3	7.14	0.16	0.00	0.00	35.66	3.50	13.43	9.64	2.23	4.59	0.00	0.00	0.00	0.00	46.58	0.00	0.00	0.96
	4	24.88	0.60	0.00	0.00	199.05	51.22	418.96	103.16	79.05	149.77	6.62	3.25	13.79	0.00	258.68	42.24	4.08	2.76
	5	664.87	54.66	9.30	50.56	0.00	28.13	124.20	27.51	158.15	70.70	5.00	466.99	257.52	11.40	522.66	12.40	2.76	66.29
	6	1464.48	39.73	0.00	197.60	210.04	0.00	23.47	163.26	173.91	346.97	17.76	3.10	34.82	13.81	140.18	364.23	78.56	142.15
	7	2947.14	63.03	0.00	304.94	314.48	45.28	0.00	8.10	10.75	14.74	0.00	3.32	18.43	3.44	16.51	60.23	198.68	297.42
	8	11.29	0.00	0.00	2.33	1.83	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	935.94	39.52	0.00	66.63	181.32	114.65	30.23	0.00	0.00	39.71	13.20	0.75	32.89	23.70	205.64	753.55	40.11	87.77
	10	551.99	21.70	0.00	40.15	229.12	70.23	21.23	0.00	24.09	0.00	9.96	0.61	22.38	13.84	552.41	450.92	27.91	55.81
	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	1467.67	147.15	0.00	0.00	428.14	7.88	0.00	0.00	21.75	1.48	0.00	0.00	6.14	7.01	99.13	180.66	13.10	166.53
	13	1845.32	200.67	0.00	18.41	519.07	107.03	0.00	0.00	27.92	1.93	0.00	6.73	0.00	6.79	26.43	230.17	11.85	171.35
	14	149.86	4.97	0.00	39.50	51.93	169.73	0.00	0.00	200.20	22.12	58.67	50.58	79.75	0.00	0.00	18.56	0.00	0.00
	15	276.02	18.88	0.00	3.00	53.23	129.57	68.46	27.07	151.11	17.59	0.00	41.69	26.52	308.42	0.00	7.90	0.63	24.81
	16	331.22	24.63	0.00	38.52	86.02	261.15	36.80	0.00	578.71	37.88	0.00	143.42	83.16	5.80	10.28	0.00	1.31	31.92
	17	319.38	22.81	0.00	0.00	10.61	25.42	71.51	19.87	131.84	26.79	0.00	23.39	14.15	0.00	37.74	1.46	0.00	36.65
	18	25.65	7.81	4.22	2.08	12.45	17.53	59.60	25.23	73.26	23.72	0.00	0.00	14.60	0.00	22.71	0.00	0.41	0.00
																			43549.55

Table 5.7: Adjusted average travel speeds per O-D pair for the base model.

VCUR new 7-8AM		**DESTINATIONS**																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0.00	28.20	21.76	21.05	18.30	19.82	20.82	17.12	19.32	20.39	19.18	14.97	14.81	16.21	15.09	17.69	15.43	10.02
	2	28.57	0.00	0.00	0.00	14.90	17.63	19.42	14.12	17.73	19.33	0.00	12.60	12.28	13.92	11.22	14.88	8.16	25.26
	3	26.92	15.18	0.00	0.00	18.52	18.24	20.82	13.44	18.08	20.06	0.00	0.00	0.00	0.00	13.09	0.00	0.00	24.23
	4	24.06	15.20	0.00	0.00	20.85	18.04	20.95	12.94	17.97	20.08	17.70	21.27	20.33	0.00	13.49	16.85	12.92	22.26
	5	21.91	11.48	25.08	23.43	0.00	23.60	25.86	16.84	20.90	22.76	20.64	12.94	12.58	14.59	11.47	16.61	13.29	20.41
	6	14.68	9.19	7.98	7.07	9.90	0.00	15.76	12.50	22.87	26.53	22.31	28.50	25.99	9.95	10.94	9.90	8.72	14.24
	7	24.79	19.31	22.88	20.61	24.72	20.10	0.00	18.37	25.67	28.73	0.00	30.41	27.93	11.20	12.14	10.99	17.15	23.34
	8	23.73	0.00	0.00	17.96	22.60	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	26.07	21.99	25.85	24.12	26.95	22.14	23.29	0.00	0.00	53.53	22.29	40.76	31.26	6.77	8.06	7.20	10.78	24.71
	10	26.98	23.32	27.60	25.92	28.47	24.79	24.36	0.00	31.15	0.00	32.20	44.58	35.29	8.16	9.39	8.37	11.71	25.59
	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	14.26	9.80	0.00	0.00	8.71	21.11	0.00	0.00	20.38	26.21	0.00	0.00	30.17	5.57	6.93	6.21	10.05	13.93
	13	14.15	9.51	0.00	26.61	8.38	25.83	0.00	0.00	33.40	39.96	0.00	31.79	0.00	4.82	6.28	5.63	9.73	13.82
	14	33.04	25.93	0.00	25.25	21.69	24.27	0.00	0.00	27.91	33.81	20.94	26.03	28.40	0.00	0.00	28.61	0.00	0.00
	15	31.51	22.43	0.00	22.74	17.62	14.51	21.86	15.29	11.50	14.02	0.00	10.43	9.65	23.62	0.00	22.70	34.75	28.54
	16	32.70	24.09	0.00	23.89	19.13	15.70	22.60	0.00	12.97	15.64	0.00	11.87	11.15	14.79	41.59	0.00	38.47	29.55
	17	27.96	11.86	0.00	0.00	12.42	16.20	17.85	13.36	12.36	13.80	0.00	11.78	11.42	0.00	9.79	13.22	0.00	24.88
	18	27.39	34.59	25.27	23.83	20.53	21.79	22.80	18.56	20.73	21.82	0.00	0.00	15.80	0.00	16.48	0.00	17.51	0.00

Table 5.8: Adjusted average travel times per vehicle per O-D pair for the base model.

t_{CUR} new 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0.00	2.98	4.28	5.18	5.80	6.85	7.02	8.41	9.26	9.48	9.26	11.35	11.01	9.93	8.07	7.03	5.61	3.86
	2	3.03	0.00	0.00	0.00	2.67	3.94	4.11	5.50	6.35	6.57	0.00	8.23	7.88	6.81	4.95	3.90	2.49	3.55
	3	3.47	1.71	0.00	0.00	2.59	2.66	2.82	4.21	5.07	5.29	0.00	0.00	0.00	0.00	4.87	0.00	0.00	3.99
	4	4.59	2.83	0.00	0.00	1.74	2.35	2.51	3.90	4.76	4.97	4.76	5.10	5.44	0.00	5.99	4.95	3.53	5.11
	5	4.90	3.45	1.65	1.55	0.00	2.67	2.83	4.23	5.08	5.30	5.08	7.15	6.80	5.72	3.86	2.82	2.34	5.42
	6	9.34	7.58	5.92	5.97	6.35	0.00	1.32	1.49	2.35	2.56	2.35	2.69	3.03	8.73	8.84	10.02	8.28	9.86
	7	6.11	4.34	2.69	2.74	3.12	5.30	0.00	1.79	2.65	2.86	0.00	2.99	3.33	9.03	9.14	10.32	5.04	6.63
	8	5.96	0.00	0.00	2.60	2.98	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	7.04	5.28	3.63	3.68	4.06	2.57	6.40	0.00	0.00	0.39	0.56	0.90	1.24	6.94	7.05	8.24	9.73	7.57
	10	7.21	5.45	3.80	3.85	4.23	2.74	6.57	0.00	0.80	0.00	0.73	1.07	1.41	7.11	7.22	8.41	9.90	7.74
	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	12.00	10.55	0.00	0.00	10.61	3.59	0.00	0.00	1.64	1.82	0.00	0.00	0.96	6.66	6.77	7.95	9.44	12.52
	13	11.61	10.16	0.00	4.12	10.22	3.02	0.00	0.00	1.06	1.25	0.00	0.91	0.00	6.26	6.38	7.56	9.05	12.13
	14	4.28	2.83	0.00	3.90	2.89	3.33	0.00	0.00	1.38	1.56	7.98	1.22	0.88	0.00	0.00	1.45	0.00	0.00
	15	3.90	2.46	0.00	3.53	2.51	6.62	5.36	5.07	4.67	4.85	0.00	4.52	4.17	0.78	0.00	1.05	1.35	4.42
	16	3.84	2.39	0.00	3.46	2.45	6.27	5.30	0.00	4.31	4.50	0.00	4.16	3.82	2.74	0.68	0.00	1.28	4.36
	17	3.14	1.69	0.00	0.00	2.50	4.44	4.60	5.99	8.21	8.40	0.00	8.06	7.71	0.00	4.78	3.73	0.00	3.66
	18	1.44	2.55	3.84	4.75	5.37	6.42	6.59	7.98	8.83	9.05	0.00	0.00	10.58	0.00	7.64	0.00	5.18	0.00

6 THE NULL ALTERNATIVE

This chapter relates back to ***Chapter 4***, and presents the results for the null alternative after the normal annual traffic growth was determined. As explained, the extrapolation of the results from the AM-peak hour to a full day was only attempted once the benefits for the AM-peak hour had been determined. The results obtained in this chapter were multiplied by 200 days in the year, though, to obtain the annual AM-peak hour travel costs.

The variables named as part of the VOT sensitivity analysis were applied in the respective calculations in this section, which led to four distinct final results for the entire network, and numerous results for the road users.

6.1 RESULTS: NORMAL TRAFFIC GROWTH

6.1.1 NORMAL TRAFFIC GROWTH FACTOR

Some growth factors were described for Stellenbosch in ***Section 4.5.1***. The analysis of historic traffic-count data, as well as probe data, was also discussed, and it is in this subsection where the results are shared, and the annual traffic growth factor for the null alternative was decided on.

The comparison between 2013 and 2015 traffic volumes at the three major signalised intersections along the R44 (R44 / Van Reede Rd, R44 / Saffraan Ave, and R44 / Dorp St), that was performed in ***Section 5.1***, did not yield any clear patterns of growth. The analysis of historic traffic-count data for the same three intersections was then extended further back to the years 2012 and 2000, for which the municipality also had documented data. The results for the southern and northern approaches of the intersections are included in ***Appendix F.1***. Again, no significant growth could be observed.

As referred to in ***Section 4.5.1***, the analysis of probe data over a five-year time span was another attempt at evaluating the average annual traffic growth rate in Stellenbosch. The outputs are shown in ***Table 6.1***, with the average sample sizes given in ***Table 6.2***. The sample sizes were looked at to ensure that enough probes were active during the earlier years. An observation that was almost the reverse of what was expected, was found though: the latter years had the smallest sample sizes for reasons that cannot be explained, since at least 5 months lie between the date of the query and the analysis period for which the data was queried. It can be seen also from these results that no consistent

Table 6.1: Comparison of probe data average speeds and cumulative travel times on the R44 corridor for 2011 to 2015.

Year	Free-flow avg. travel speed (km/h)	AM-peak avg. travel speed (km/h)	Free-flow avg. cumulative travel time (min)	AM-peak avg. cumulative travel time (min)	Avg. travel time delay (min)
2015	79.22	29.96	4.82	12.74	7.92
2014	74.34	28.85	5.13	13.28	8.15
2013	73.50	27.16	5.19	14.05	8.86
2012	74.83	28.91	5.10	13.20	8.10
2011	68.65	28.35	5.56	13.46	7.90

Table 6.2: Average probe data sample sizes for the R44 corridor for 2011 to 2015.

Year	Base set avg. sample size	AM peak avg. sample size
2015	9.4	32.5
2014	17.67	99.0
2013	85.5	229.97
2012	24.37	199.07
2011	37.2	122.37

growth occurred over the five years. The average travel time delay for 2015 is almost identical to that of 2011; for the years in between, the average travel time delays were slightly higher, but the variance was taken to be statistically insignificant.

The next step was then to look for growth outside of the AM-peak hour, and this is where the growth that was known to exist, was found. Referring back to ***Appendix F.1***, it is in the hour between 06:00 and 07:00 that the traffic grew a great deal from 2000 to 2012, 2013 and 2015. For 2015, data was unfortunately only available for the 15-min period between 06:45 and 07:00. The annual traffic growth rates between 2000 and 2013 ranged from 7.4% to 9.1%, and 10.3% to 11.3 %, respectively, for the southern and northern approaches of the intersections defined at the beginning of the subsection. It thus seems that the roads have been congested near to capacity during the 07:00-to-08:00 time period since 2000 (and possibly even before then), and that the annually generated surplus traffic was forced to spill over to an earlier time period. This phenomenon is referred to as peak spreading, which was introduced in ***Section 1.2*** and defined in ***Section 4.7.9***. Most commuters still need to be at either school, campus or work before 08:00, which is why the congestion spreads backwards to an earlier time period instead of forwards to a later time period. This peak-spreading trend is what the null alternative of this research project is all about.

Although extremely high traffic growth rates were found to exist for the early hours of the day, the average annual AM traffic growth rate for Stellenbosch was assumed to only be 3% for the duration of the project life, based on the population and economic growth factors referred to at the beginning of this subsection.

In a complex road network that serves a variety of origins and destinations, peak spreading could, to varying extents, divert vehicle trips to different routes or travel modes during the evaluation period. This likely happening is ignored in this research project, however, for simplicity motives, but also since few alternative routes and no real alternative modes are available to the road users.

6.1.2 NORMAL TRAFFIC GROWTH: VOLUMES OVER 20-YEAR SPAN

The default capacity of 2,600 veh/h for a 2-lane primary link type, i.e. the R44 corridor, was accepted and applied in the Visum model. The annual 3% growth factor was thus applied to the observed 2015 traffic flow of the R44 corridor during the AM-peak period until the capacity of 2,600 veh/h was reached. The ICA performed for the R44 / Van Reede intersection found the capacity of the southern approach to be 2,528 veh/h, so 2,600 veh/h was seen to be an acceptable capacity for the corridor. The year in which capacity is reached was then taken to be the year in which peak spreading for the entire network begins. The number of vehicles above this limit were seen as the spillover to the earlier time period. The benefit analysis of this research project thus not only evaluated the positive impact that bicycle-sharing can potentially have on the AM-peak-hour congestion, but also to which extent it can reduce, or even eliminate, the spillover to the earlier hours of the day.

Table 6.3 shows the traffic volumes on the R44 corridor for the years 2015 to 2034 that will arise as a result of a 3% annual traffic growth, and the total number of vehicles that will spillover to the earlier time period every year once capacity is reached. As mentioned, the system is to be launched in 2020. This means that it will only take 2 years for the peak spreading to begin. By the end of 2034, the spillover will comprise a number of vehicles that equals more than half of what was counted on the corridor in 2015 for the AM-peak hour.

Table 6.3: 20-year traffic growth on the R44 corridor and the resulting spillover to an earlier time period once capacity is reached.

Year	Traffic volume with 3% annual traffic growth after 2015 (veh)	Spillover to earlier time period (veh)
2015	2,113	
2016	2,176	
2017	2,242	
2018	2,309	
2019	2,378	
2020	2,451	
2021	2,523	
2022	2,599	
2023	2,677	77
2024	2,757	157
2025	2,840	240
2026	2,925	325
2027	3,013	413
2028	3,103	503
2029	3,196	596
2030	3,292	692
2031	3,391	791
2032	3,492	892
2033	3,597	997
2034	3,705	1,105

6.2 RESULTS: NULL-ALTERNATIVE TRAVEL COSTS

For the null alternative, new O-D matrices had to be created, and new delays on the links and at the nodes calculated, which reflect the annual traffic growth. This was done as described in ***Section 4.5.1.*** Using Visum's *Calculate PrT skim matrix* procedure, the VMT, VHT and mean system speed were then calculated for the AM-peak period for the years 2020, 2021 and 2022. After 2022, these parameters were assumed to remain constant. The total VOCs and travel time costs were evaluated using the formulas defined in ***Section 4.7.3***, and the CO_2 emissions as explained in ***Section 4.7.6***. The health and accident expenses of the null alternative were taken to be zero, and the benefits relating to health and accident costs were hence determined relative to this null alternative.

As a reminder, the null alternative only refers to the travel conditions of the AM-peak hour. Although peak spreading was found to occur, the travel costs were not quantified for the earlier time period, because of the complexity to do so. The number of vehicles currently travelling at this time of day was unknown, and the signal timing is completely dissimilar at these earlier hours of the day compared to the AM-peak hour, due to fewer green-time calls coming from the side streets.

The null-alternative average travel time and average travel speed were also assessed per road-user group as input to their VOC and travel-time-cost equations. All school trips were taken to have their origin in zone 1 and their destination in zone 14, and for the SU students and SU staff, VOCs and travel time costs were determined for each of the route options identified during the analysis of the travel survey results (see ***Section 12.1***). These routes were numbered from 1 to 4 as follows:

1. from zone 1 to zone 7 (R44 downstream)
2. from zone 1 to zone 9 (via Dorp St into Mill St)
3. from zone 1 to zone 12 (via Van Reede Rd to Suidwal Rd)
4. from zone 1 to zone 13 (via Van Reede Rd to Noordwal-Wes Rd)

No CO_2 emissions, and hence no fuel consumption, were calculated per road user, because these emissions relate to costs that are not directly carried by the user.

The spreadsheets with the detailed calculations are provided on the attached CD.

6.2.1 NULL ALTERNATIVE: O-D MATRICES AND LINK / TURN DELAYS

The null-alternative O-D matrices are given in ***Appendix F.2***. The null-alternative link and turn travel times are presented in ***Appendix F.3*** per vehicle per O-D pair; delays are also given per turn movement.

6.2.2 NULL ALTERNATIVE: VMT, VHT AND MEAN SYSTEM SPEED

Table 6.4 shows the VMT, VHT and mean-system-speed results for the null alternative. As for the prevailing conditions, these values were evaluated for the full network. The 2015 values were included for comparative purposes. A steady decline in the mean system speed was found, with the mean speed at capacity being almost half of the 2015 value. The null-alternative VMT and VHT matrices are attached as ***Appendix F.4***.

Table 6.4: AM VMT, VHT and mean system speed for the null alternative.

Year	VMT (km)	VHT (h)	Mean system speed (km/h)
2015	13,157	726	18.13
2020	15,349	1,522	10.09
2021	15,810	1,818	8.69
2022 to 2034	16,284	2,167	7.51

Table 6.5 gives the travel distance, average travel time and average travel speed per road user per year for the null alternative. For the school trips, only the parents were considered, because it is them that carry the travel costs. The delay encountered on the 288-m road segment between zone 1 and the intersection of the R44 and Trumali St, was assumed to cancel out with that to be come across later at the Drop-and-Go and Park-and-Ride.

Table 6.5: travel distance, AM average travel time and AM average travel speed per road user for the null alternative.

Year / Road user	AM travel distance (km)	AM average travel time (min)	AM average travel speed (km/h)
2015			
school parents	5.04	14.21	21.28
SU students and staff 1	2.44	9.26	15.77
SU students and staff 2	2.98	7.02	25.50
SU students and staff 3	2.83	11.35	14.97
SU students and staff 4	2.72	11.01	14.81
2020			
school parents	5.04	23.90	12.65
SU students and staff 1	2.44	13.30	10.98
SU students and staff 2	2.98	19.16	9.34
SU students and staff 3	2.83	19.40	8.76
SU students and staff 4	2.72	18.95	8.61
2021			
school parents	5.04	28.02	10.79
SU students and staff 1	2.44	15.40	9.49
SU students and staff 2	2.98	22.38	8.00
SU students and staff 3	2.83	22.32	7.61
SU students and staff 4	2.72	21.83	7.47
2022 to 2034			
school parents	5.04	32.77	9.23
SU students and staff 1	2.44	17.66	8.27
SU students and staff 2	2.98	25.84	6.93
SU students and staff 3	2.83	25.70	6.61
SU students and staff 4	2.72	25.17	6.48

6.2.3 NULL ALTERNATIVE: ROAD USER COSTS

6.2.3.1 NULL ALTERNATIVE: VOC

Table 6.6 shows the null-alternative VOCs for the entire network per year, as well as the total present-worth VOC over the service life of the system, which is approximately ZAR 387 million.

The null-alternative annual VOCs per road-user group are given in ***Table 6.7***. When analysing the results, it must be remembered (as for all the results given in this section) that VOCs apply only to the AM commute and only for those parts of the trip that fall within the study area.

As mentioned, the complete calculation sheets are provided on the attached CD.

Table 6.6: AM VOCs of the entire network for the null alternative.

Year	VOC (ZAR)
2020	26,754,623
2021	29,765,430
2022 to 2034	33,217,544
Total PWOC $_{VOC}$	387,020,250

Table 6.7: AM VOCs for the null alternative per road-user group

Road user	VOC (ZAR)		
	2020	2021	2022 to 2034
school parents	7,873	8,494	9,195
SU students and staff 1	4,069	4,380	4,709
SU students and staff 2	5,408	5,877	6,375
SU students and staff 3	5,311	5,735	6,220
SU students and staff 4	5,145	5,562	6,041

6.2.3.2 NULL ALTERNATIVE: TRAVEL-TIME COSTS

For the travel-time-cost calculation for the entire network, an average hourly wage was applied to all the road users: the R120/h found for the SU staff. In ***Tables 6.8***, the null-alternative travel-time-cost results for the entire network per year are summed up for a vehicle occupancy of 1.5 and 1.2. In each row, two totals are given that relate to a difference in the VOT for commuting:

1. obtained from applying a factor of 0.5 to the hourly wage rate, and
2. obtained from applying a factor of 0.25 to the hourly wage rate.

The four resulting cases are henceforth referred to as VOT 1, VOT 2, VOT 3 and VOT 4.

The null-alternative present-worth travel time costs for the service life of the system range from just about ZAR 179 million to ZAR 449 million.

Table 6.8: Travel AM time cost for the null alternative of the entire network for VOT 1, VOT 2, VOT 3 and VOT 4.

Year	VOT 1 (ZAR); vehicle occupancy 1.5, factor = 0.5	VOT 2 (ZAR); vehicle occupancy 1.5, factor = 0.25
2020	27,391,575	13,695,786
2021	32,729,944	16,364,972
2022 to 2034	39,013,992	19,506,996
Total PWOC $_{VOT}$	448,539,286	224,269,643
	VOT 3 (ZAR); vehicle occupancy 1.2, factor = 0.5	VOT 4 (ZAR); vehicle occupancy 1.2, factor = 0.25
2020	21,913,260	10,956,630
2021	26,183,955	13,091,978
2022 to 2034	31,211,194	15,605,597
Total PWOC $_{VOT}$	348,814,790	179,415,714

Table 6.9 gives the total travel time costs per road user. For these calculations the individual VOT of each road user, as defined in ***Section 4.5.2.4.1***, was applied. This means that there are no travel-time expenses for the scholars. Although the average annual VOC for all the school parents is identical, separate travel time costs had to be computed for the non-working and working parents. Because travel time costs are directly related to the hourly income rate and travel distance of the road user, the greatest travel time costs lie with the working school parents.

6.2.4 NULL ALTERNATIVE: ENVIRONMENTAL EMISSIONS

Table 6.9: Total AM travel time costs for the null alternative per road user.

Road user	2020	2021	2022 to 2034
	VOT (ZAR)		
non-working school parents	637	747	874
SU students 1	355	411	471
SU students 2	511	597	689
SU students 3	517	595	685
SU students 4	505	582	671
	VOT 1 (ZAR); factor = 0.5		
working school parents	15,135	17,748	20,754
SU staff 1	2,660	3,081	3,531
SU staff 2	3,832	4,476	5,168
SU staff 3	3,879	4,464	5,140
SU staff 4	3,790	4,365	5,034
	VOT 2 (ZAR); factor = 02.5		
working school parents	7,567	8,874	10,377
SU staff 1	1,330	1,540	1,766
SU staff 2	1,916	2,238	2,584
SU staff 3	1,940	2,232	2,570
SU staff 4	1,895	2,183	2,517

6.2.4.1 NULL ALTERNATIVE: FUEL CONSUMPTION

The average null-alternative fuel consumptions per year for the entire network, required for the CO_2-emissions calculations, are shown in ***Table 6.10***. Fuel consumptions above 23 l/100km were computed for all the years.

Table 6.10: Average AM fuel consumption for the null alternative of the entire network.

Year	Fuel consumption (l/100km)
2020	23.05
2021	25.58
2022 to 2034	28.40

6.2.4.2 NULL ALTERNATIVE: CO_2 EMISSIONS

The null-alternative CO_2 emissions for the entire network per year were first expressed in tonnes before the monetary value was assigned. The results are shown in ***Table 6.11***. A total PWOC of ZAR 16,112 was calculated over the service life of the system, which is low relative to the other travel cost.

Table 6.11: AM CO_2 emissions for the null alternative.

Year	Fuel consumption (l/100km)	CO_2 emissions (t)	CO_2 emissions (ZAR)
2020	23.05	8.85	1,062
2021	25.58	10.12	1,224
2022 to 2034	28.40	11.57	1,389
Total PWOC $_{CO2}$			16,112

Every additional tonne of CO_2 is seen to have a more harmful effect on the environment, though, than this value leads one to believe it has.

6.2.5 NULL ALTERNATIVE: TOTAL TRAVEL COSTS

The final PWOC results (over the service life of the system) for the null alternative and entire network are presented in ***Table 6.12***. The totals range from about ZAR 0.57 billion to ZAR 0.84 billion.

Table 6.13 presents the total null-alternative travel costs per road user over the service life of the system. The highest costs are felt by the school parents who are exposed to traffic congestion the longest. It can be seen that, in the case of the SU staff and working school parents, the travel-time costs contribute significantly to the total travel costs, and hence the factor (either 0.5 or 0.25) by which the hourly wage rate is multiplied by, has s noteworthy effect on the final result.

Table 6.12: Total AM travel costs (over the service life of the system) for the null alternative of the entire network for the various cases of VOT.

Option	Total $PWOC_{\_ \text{null alternative}}$ (ZAR)
with VOT 1	835,575,647
with VOT 2	611,306,004
with VOT 3	735,851,151
with VOT 4	566,452,075

Table 6.13: Total AM travel costs for the null alternative per road user over the service life of the system.

Road user	2020	2021	2022 to 2034
non-working school parents	8,510	9,241	10,069
SU students 1	4,424	4,791	5,180
SU students 2	5,919	6,474	7,064
SU students 3	5,828	6,330	6,905
SU students 4	5,650	6,144	6,712
	VOT 1 (ZAR); factor = 0.5		
working school parents	23,008	26,242	29,949
SU staff 1	6,729	7,461	8,240
SU staff 2	9,240	10,353	11,543
SU staff 3	9,190	10,199	11,360
SU staff 4	8,935	9,927	11,075
	VOT 2 (ZAR); factor = 0.25		
working school parents	15,440	17,368	19,572
SU staff 1	5,399	5,920	6,475
SU staff 2	7,324	8,115	8,959
SU staff 3	7,251	7,967	8,790
SU staff 4	7,040	7,745	8,558

7 RESULTS: SUMMARY OF TRAVEL SURVEYS

Before the feasibility of implementing a bicycle-sharing scheme is assessed, this chapter provides an overview of the survey results. A sample of each questionnaire is given in ***Appendix C***, and a spreadsheet of all the results is included on the CD submitted with this document. These results are what re-confirm the need for a congestion-relief solution, shape the ultimate design of the bicycle-sharing scheme, and determine the potential of the scheme to yield benefits. For argumentative purposes, some of these results have been referred to in previous chapters, but they will be presented again in full context here. Only the average annual income of the school parents, which was included in the discussion and calculation of VOT, will not be given again. The results of the potential-user and station-location calculations form part of ***Chapter 8***.

7.1 SCHOOL SURVEY

7.1.1 RESPONSE RATES / SAMPLE SIZES

For the schools Bloemhof Girls' High, Paul Roos Gymnasium and Rhenish Girls' High, the response rates were as follows:

- 209 households (equivalent to 236 learners) responded out of the Bloemhof Girls' High learner population of 709, i.e. response rate = 33.3%;
- 329 households (equivalent to 395 learners) responded out of the Paul Roos Gymnasium learner population of 1200, i.e. response rate = 32.9%; and
- 127 households (equivalent to 142 learners) responded out of the Rhenish Girls' High learner population of 691, i.e. response rate = 20.5%.

The total response of the three schools is thus 665 households (equivalent to 773 learners) out of a learner population of 2600 learners, which is a response rate of 29.7%. Although this is a relatively high response rate, as mentioned in ***Section 4.7.1***, confidence levels were applied to all of the results obtained from calculations that utilised the school-survey data.

7.1.2 PERCEPTIONS OF CURRENT TRAFFIC CONDITION

Whilst the rating parents gave to the current traffic conditions *en route* to and in direct vicinity of their respective schools was already reported on in ***Section 1.1.3.2***, these ratings were averages for all the nine surveyed schools, and thus not specific to Bloemhof Girls' High School, Paul Roos Gymnasium and Rhenish Girls' High. New figures that show only the findings of the three schools were thus drawn. The ratings again highlight the unsustainability of the current traffic congestion and the urgent need for a modal shift towards NMT. When the respondents (of the three schools included in this study) were asked to compare the traffic congestion within close proximity of the schools to that encountered on the rest of the travelled route, 54% indicated that the congestion around the school is *"a lot worse"* (see ***Figure 7.1***). The respondents rated the level of AM-peak congestion within close proximity of the school as an average of 7.6 out of 10, with 10 being the worst rating of congestion (bumper-to-bumper). 74.2% of the respondents rated this AM congestion to be 7 out of 10 and higher (*see* ***Figure 7.2***).

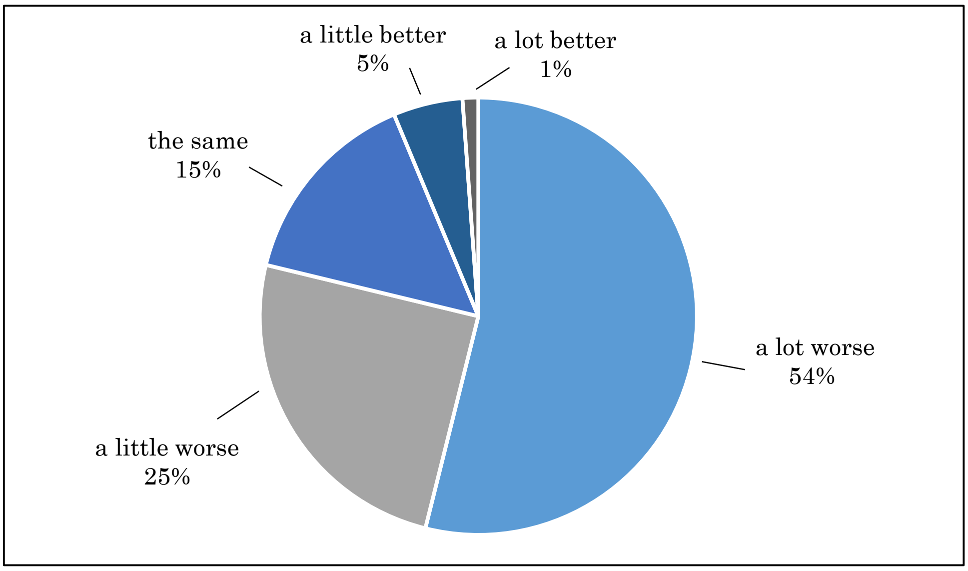


Figure 7.1: Survey responses relating to the comparison of congestion in close proximity of the three schools and the rest of the travelled route.

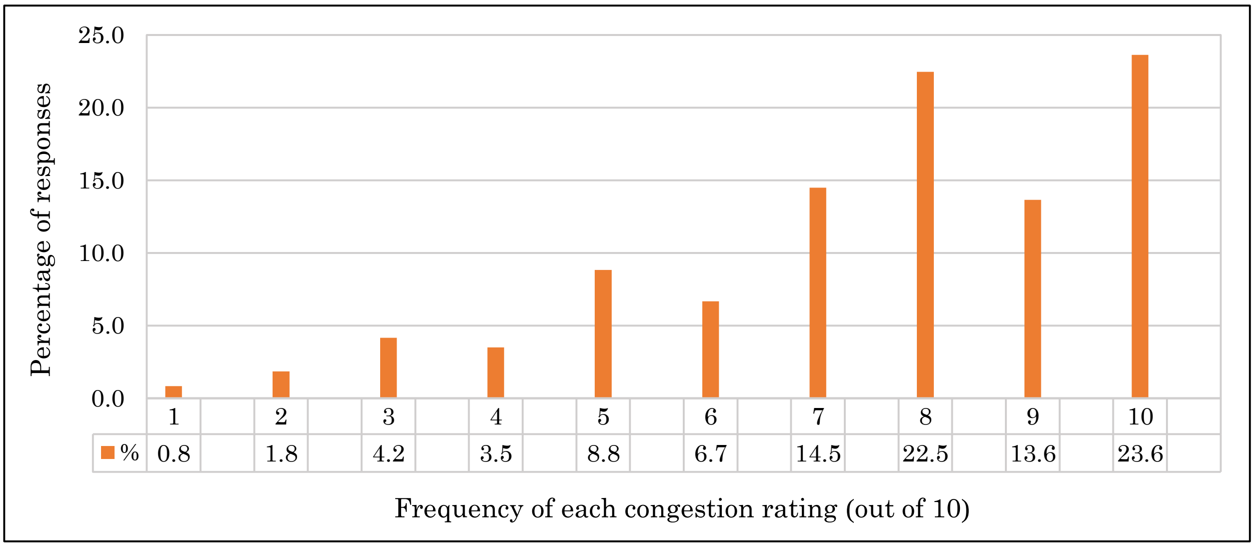


Figure 7.2: Rating given by school parents to the traffic congestion within close proximity of the school.

Figure 7.3 shows that the respondents rated their level of frustration resulting from the current congestion situation as an average of 7.6 out of 10, with 10 being the highest level of frustration. These results are a testimony of the likely conveniences and benefits a bicycle-sharing scheme operating from Drop-and-Go zones (sited upstream of the recurrent congestion 'hotspots') would be able to bring to the parents of the scholars who commute to school in a private motor vehicle on a daily basis.

7.1.3 MODAL SHARES

Modal share, along with trip origin, was the most important output of the school-travel survey, as it was important to ascertain how many private-motor-vehicle trips the bicycle-sharing scheme would be able to eliminate (at least from a certain point along the route onwards).

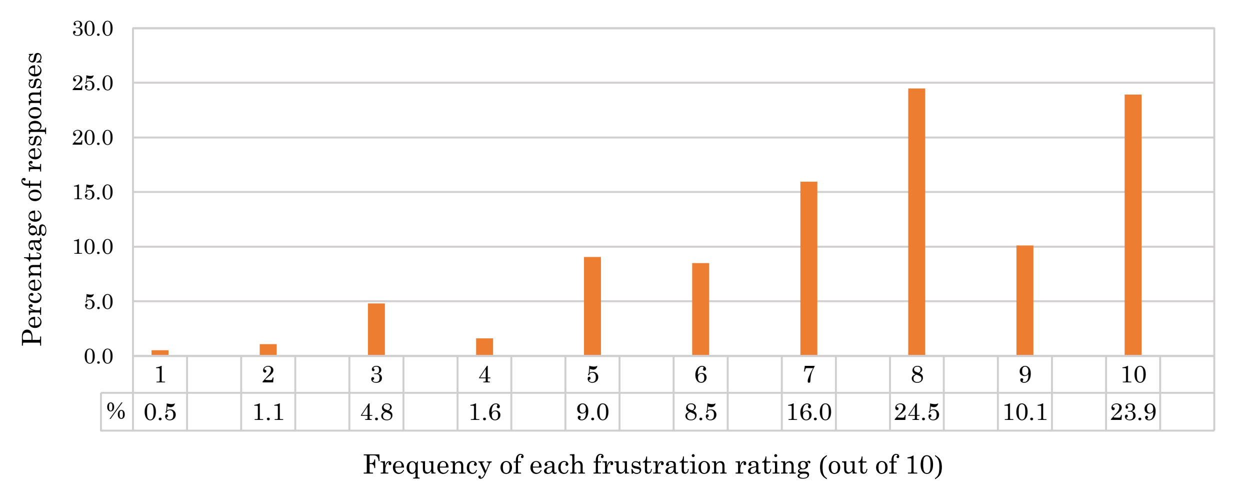


Figure 7.3: Rating given by school parents to the level of their frustration towards the traffic congestion within close proximity of the school.

The modal share of the respondents is as shown in ***Figure 7.4***. There were a total of 765 responses for the mode choice question. Only 112 respondents (14.7%) make use of active transportation (walking and cycling); this includes the boarders who walk to school (77 out of 713 responses = 10.8% of the respondents to the boarding school question). 653 respondents (85.4%) thus make use of motorised transportation modes, of which 76.2% use the private motor vehicle – a figure that points towards scheme benefits at least pertaining to traffic congestion.

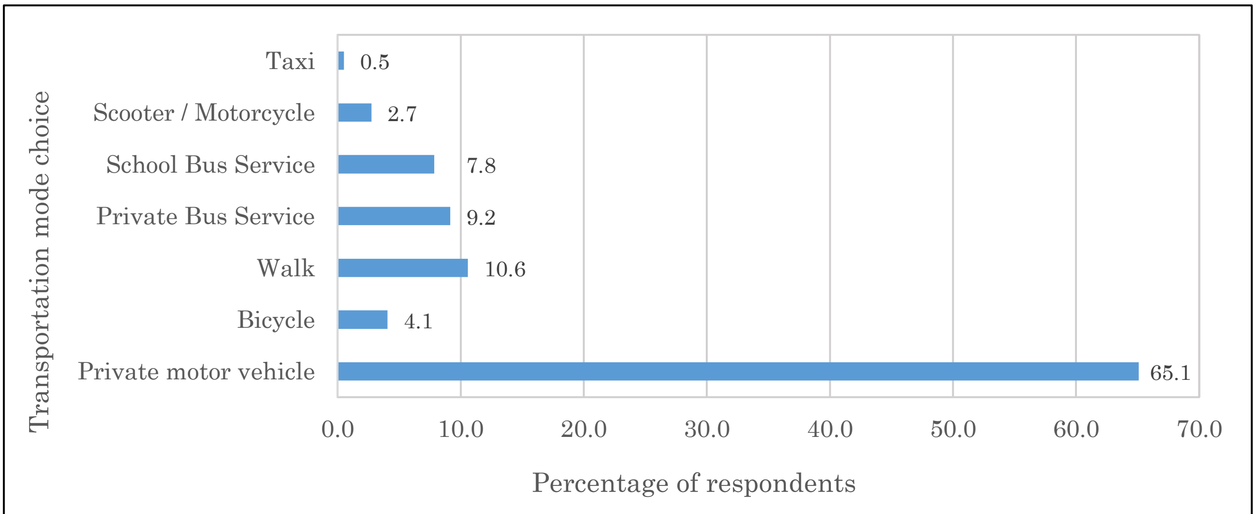


Figure 7.4: Total modal share for Bloemhof Girls' High, Paul Roos Gymnasium and Rhenish Girls' High in 2014.

7.1.4 TRIP ORIGINS

As stated in the previous subsection, knowledge of the trip origins was necessitated along with the modal shares to determine the potential benefits of bicycle-sharing. The total number of private-motor-vehicle trips per origin also helped define the study area for the case study at the very beginning of this research project, and also assisted with the delineation of the Drop-and-Go zones. Data from the respondents revealed that the learner population of the three schools comprises a total of 52.1%

learners (i.e. over half) that either reside on the outskirts of the town of Stellenbosch or beyond its boundaries (see ***Figure 7.5***). The trip origins named on the graph are all suburbs / areas within Stellenbosch. It is the learners making use of private motor vehicles from (and to) the trip origin (and destination) "other*"* that the bicycle-sharing scheme intends to address. Of the other suburbs named though, not all are necessarily unsuitably located to form part of the scheme.

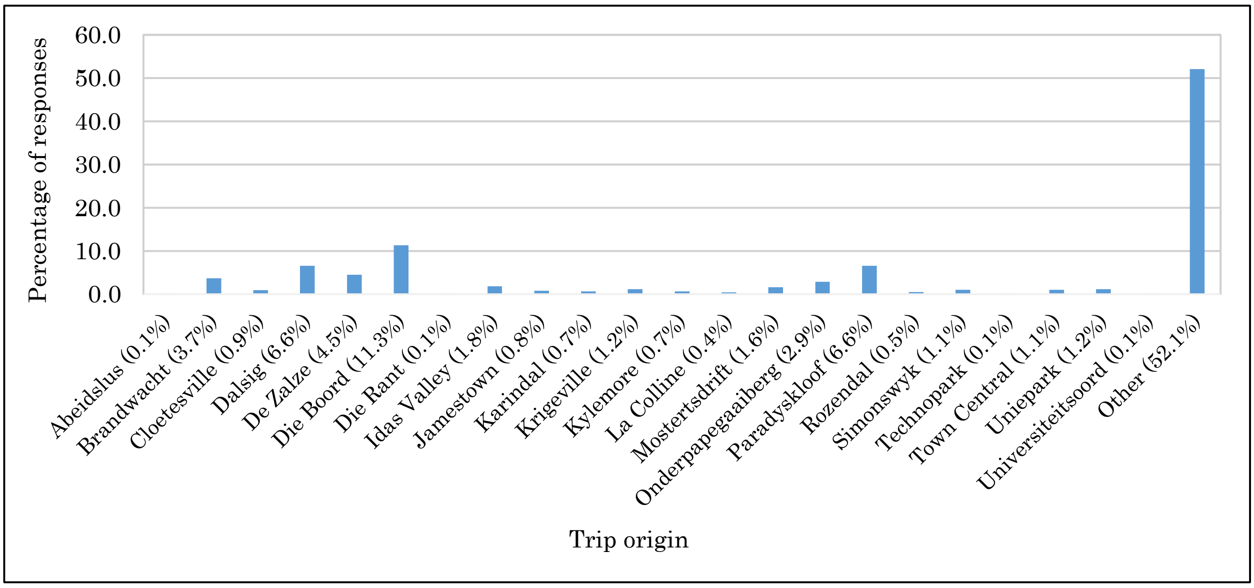


Figure 7.5: Total proportions of trip origins of the respondents from Bloemhof Girls' High, Paul Roos Gymnasium and Rhenish Girls' High in 2014.

7.1.5 BARRIERS PREVENTING ACTIVE TRANSPORTATION

For the design of the bicycle-sharing scheme, it was imperative to deliberate on the barriers that currently prevent active transportation from reigning as THE modes of transportation to and from school. For the survey respondents, the barriers preventing active transportation are shown as a percentage of responses in ***Figure 7.6***. Respondents could name more than one barrier.

"Travelling distance too long" is the prime barrier (57.4%), which again verifies that the cycling mode can in, most cases, only be promoted in conjunction with Drop-and-Go zones. The second most frequently named barrier is "too much / heavy baggage", identified by 44.4% of the respondents. Furthermore, safety and security concerns, as well as inclement weather conditions, prevent the scholars from travelling to school either by bicycle or on foot on an every day. These hindrances to cycling and walking are in line with those identified during the literature review.

In ***Section 9.4*** it is shared, how these identified barriers will be addressed for a successful implementation of the proposed bicycle-sharing scheme for Stellenbosch. The deliberation of the road safety aspect is of utmost importance, since, as stated by Sinclair *et al.* (2012), "there can be no sustainable development when the prevailing transportation systems allow for loss of life and lack of human safety…". It is ironic though, that many parents who drive their child/ren to and from school by private motor vehicle, do so because of concerns about safety from motorised traffic, and yet in doing

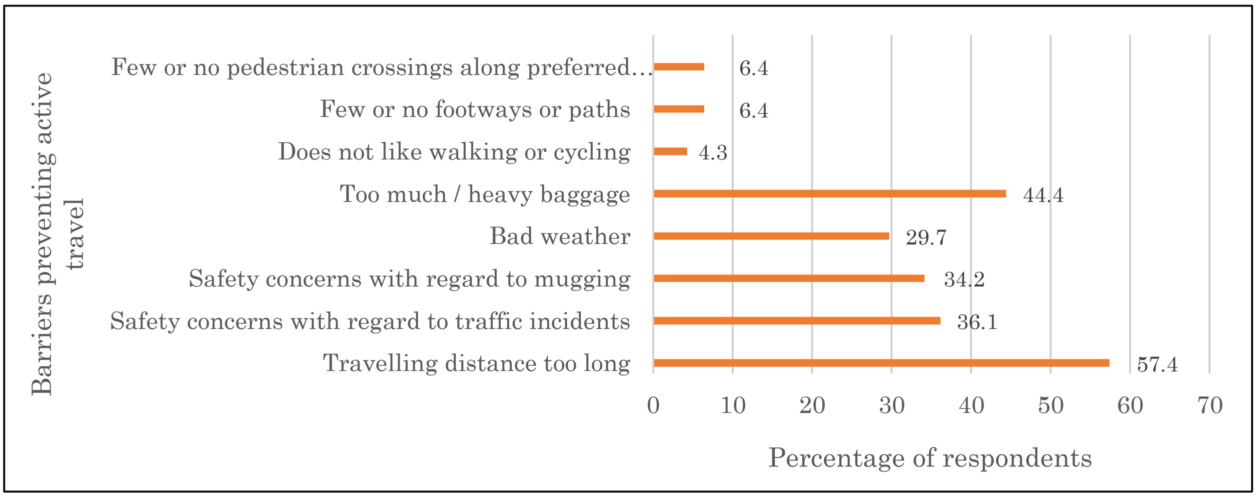


Figure 7.6: Barriers preventing active transportation for school travel in 2014.

so, contribute to the congestion on the roads and around the school gates that gives rise to these concerns.

7.2 STELLENBOSCH UNIVERSITY STUDENTS AND STAFF

Although the survey results for the SU students and staff are presented in the same subsection here, the results for the two road-user groups will be given separately.

7.2.1 RESPONSE RATES / SAMPLE SIZES

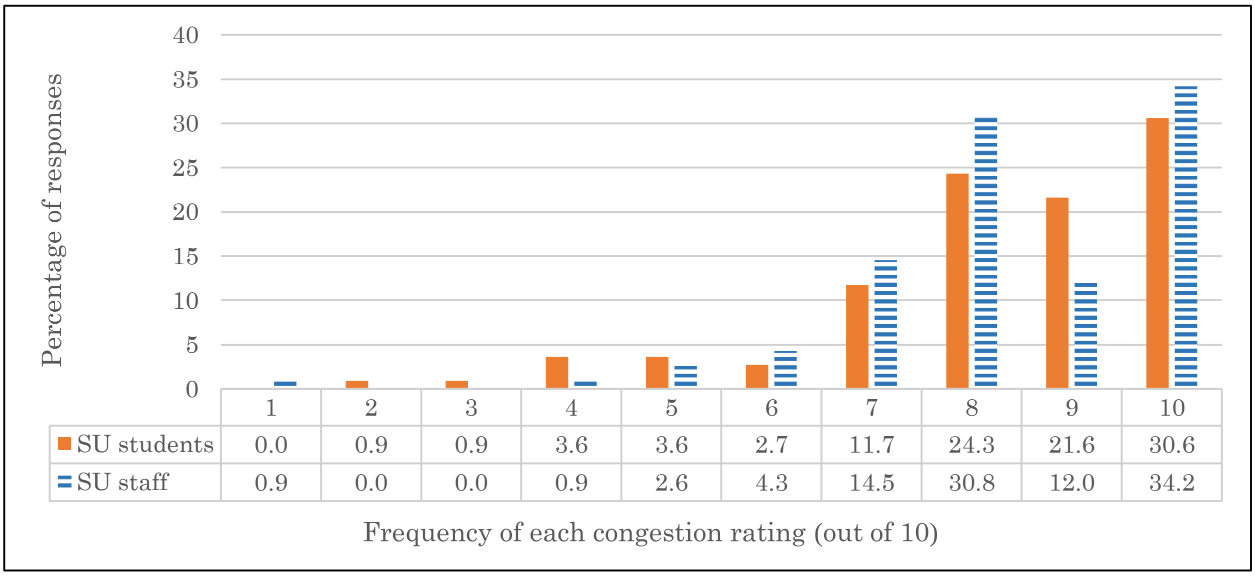
The response rates per road-user group were calculated only from those responses where the respondent indicated that his / her daily trip to the SU campus entails travelling along the R44 from the direction Somerset West. The results were as follows:

- 114 SU students responded out of the total student population of 915 that resides in the southern suburbs / towns of / to Stellenbosch, i.e. response rate = 12.5%; and
- 125 SU staff members responded out of the total staff population of 367 that resides in the southern suburbs / towns of / to Stellenbosch, i.e. response rate = 34.1%.

Again, confidence levels were applied to the results of all the calculations that used SU survey data as an input.

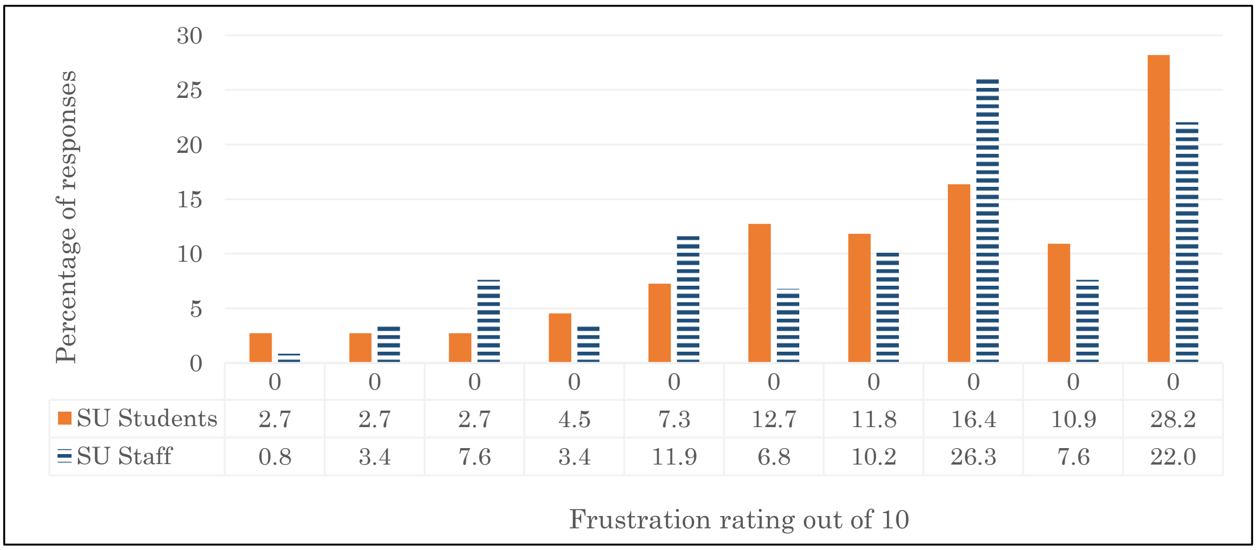
7.2.2 PERCEPTIONS OF CURRENT TRAFFIC CONDITION

In ***Figure 7.7*** the rating SU respondents gave to the AM peak hour traffic congestion within 2 km of the Stellenbosch University campus is displayed. The average rating given by the SU students and staff, respectively, is 8.3 and 8.4 out of 10, where 10 is again the worst rating of congestion (bumper-to-bumper). These ratings are high, with approximately 77.0% of the SU respondents (both SU students and staff) giving a ranking of 8 out of 10 or higher. The associated frustration ratings were specified as 7.4 for the SU students and 7.1 for the SU staff (see ***Figure 7.8***).



	1	2	3	4	5	6	7	8	9	10
SU students	0.0	0.9	0.9	3.6	3.6	2.7	11.7	24.3	21.6	30.6
SU staff	0.9	0.0	0.0	0.9	2.6	4.3	14.5	30.8	12.0	34.2

Figure 7.7: Ratings given by SU students and staff to traffic congestion within 2 km of the campus.



	0	0	0	0	0	0	0	0	0	0
SU Students	2.7	2.7	2.7	4.5	7.3	12.7	11.8	16.4	10.9	28.2
SU Staff	0.8	3.4	7.6	3.4	11.9	6.8	10.2	26.3	7.6	22.0

Figure 7.8: Ratings given by SU students and staff to the level of their frustration towards the traffic congestion within close proximity of the campus.

7.2.3 VIEW ON CYCLING DEVELOPMENT

The SU respondents were asked to give their view on the following statement: "I support changes to cycling development and the provision of cycling facilities in Stellenbosch". The responses are revealed in ***Figure 7.9***. A total of 78.1% of the SU-student and 70.9% of the SU-staff respondents agreed to the statement, with 46.5% and 43.6%, respectively, agreeing strongly. These views, along with the high ratings of congestion, are a verification that the need for NMT exists at least in direct proximity of the SU campus.

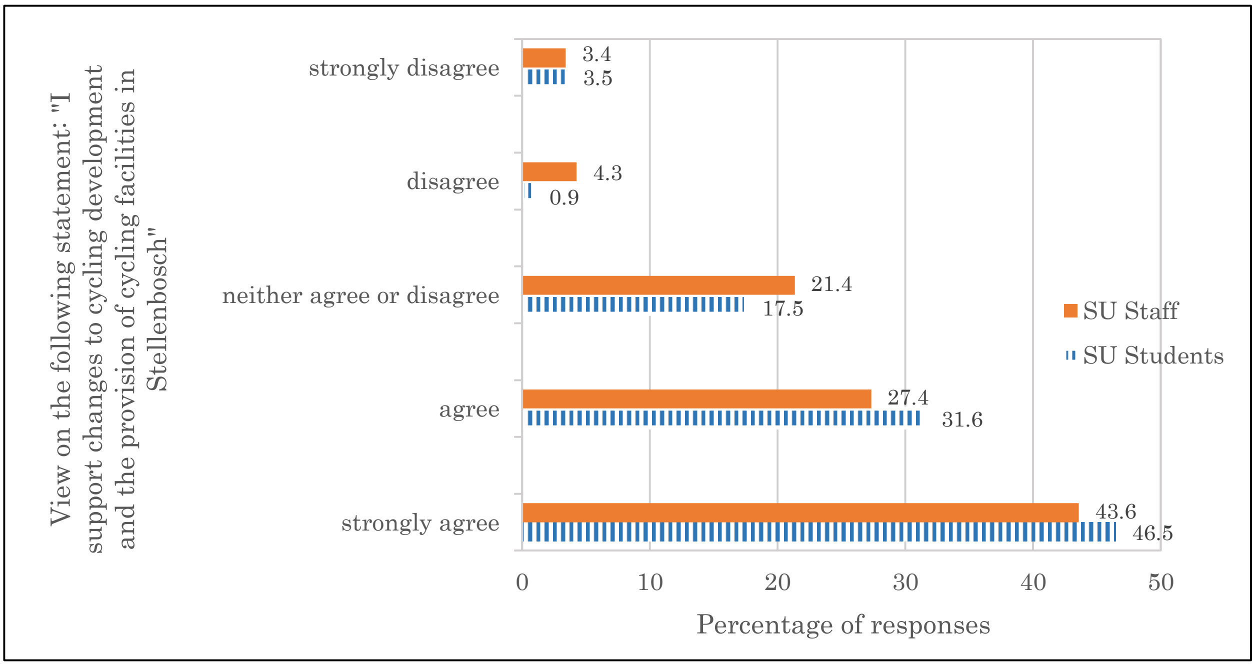


Figure 7.9: The views of the SU respondents to the following statement: "I support changes to cycling development and the provision of cycling facilities in Stellenbosch".

7.2.4 MODAL SHARES

The 2015 total modal shares for the SU students and staff residing in the southern suburbs / towns of / to Stellenbosch are shown in ***Figure 7.10***. It is evident from the figure that the car is king of the modes for both road-user groups. The SU students are less often the driver of the private motor vehicle and more often a passenger though than is the case for the SU staff. 34 out of 109 SU-student

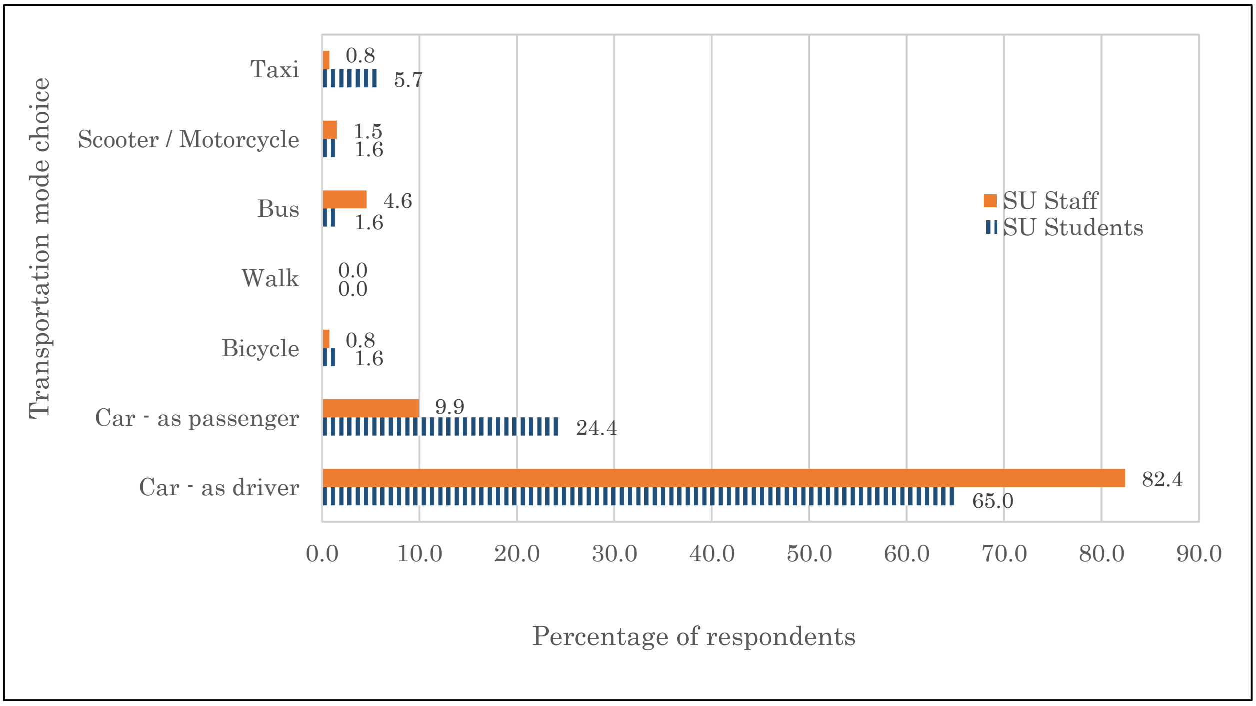


Figure 7.10: 2015 total modal share of SU students and staff residing in the southern suburbs / towns of / to Stellenbosch.

respondents and 21 out of 118 SU-staff respondents indicated that they are part of a lift club. ***Table 7.1*** shows the number of persons per specified lift club. It is possible that some of the lift clubs refer to the same one, as more than one member of the lift club may have responded to the survey.

Table 7.1: The number of persons per specified lift club for SU students and SU staff in 2015.

Number of other persons, i.e. excl. the driver, per specified lift club	Number of lift clubs	
	SU students	SU staff
1	16	11
2	9	4
3	7	3
4	2	2
5	0	1

7.2.5 AVERAGE ACCEPTABLE CYCLING DISTANCE

The mean, median and mode of the answers to the question that asked the respondents to state the maximum acceptable distance they would cycle to the SU campus if it is assumed that "travelling distance is too far" is the only barrier preventing them from cycling to campus on a daily basis, are given in ***Table 7.2***. The median and mode were included as part of the results, because some respondents indicated a maximum acceptable cycling distance for a one-way trip of around 40 km, which skews the data when only the mean is considered. For both the SU students and staff, the maximum acceptable cycling distance seems to be 5 km. Although the literature review found the average acceptable cycling distance to vary with age, fitness, cycling skills of the individual cyclist, as well as whether the bicycle is a choice or a captive mode of transportation, the average acceptable cycling distance of 5 km is similar to what was observed internationally.

Table 7.2: Maximum acceptable cycling distance indicated by SU students and staff.

	Maximum acceptable cycling distance (km)	
	SU students	SU staff
mean	7.53	6.55
median	5.00	5.00
mode	5.00	5.00

7.2.6 TRAVELLING DISTANCE

Figure 7.11 portrays the travelling distances from home to the SU campus for the SU-student and SU-staff road-user groups residing in the southern suburbs / town of / to Stellenbosch. The majority of the trip makers have travelling distances that are longer than the average maximum acceptable cycling distance identified above, which once more confirms the need of Park-and-Rides in combination with the bicycle-sharing scheme.

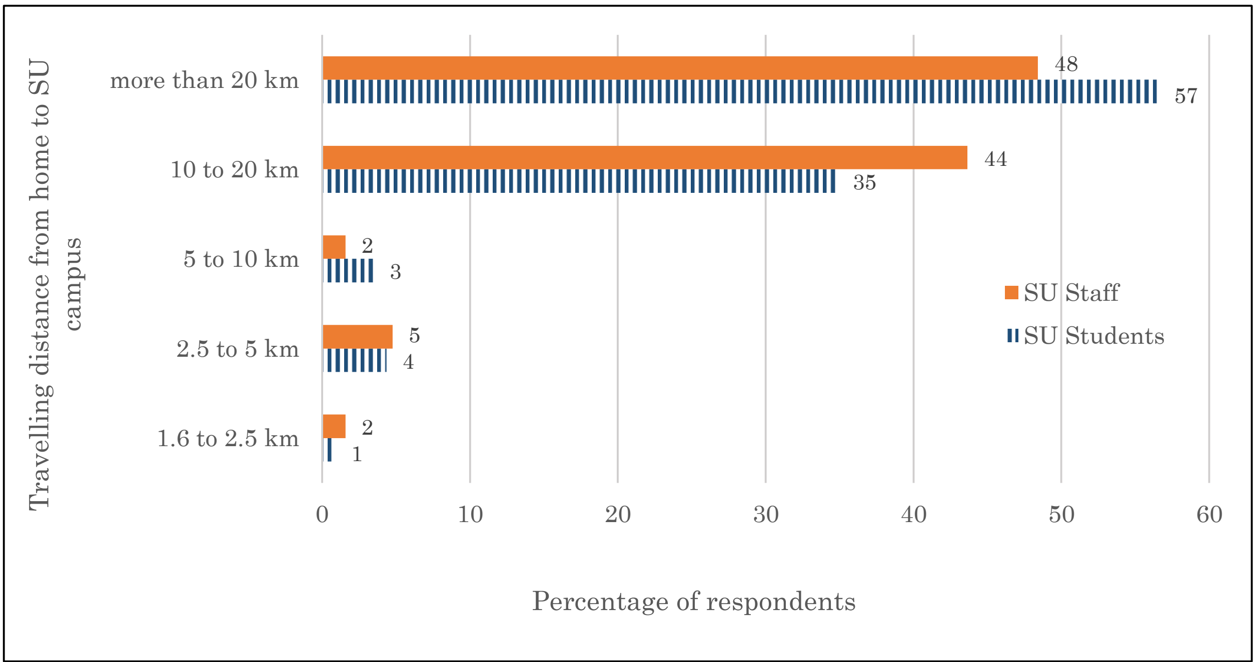


Figure 7.11: Travelling distances from home to the SU campus for the SU-student and SU-staff respondents.

7.2.7 TRAVEL TIME

The time of travel of the SU-student and SU-staff respondents were required for the potential-users calculations. The results of the travel-time question are provided in the sheets on the attached CD.

7.2.8 FIELD OF STUDY / WORK

The field of study / work of the SU-student and SU-staff respondents was required for the station-location calculations. The results of the field-of-study/work question are therefore provided in ***Section 9.3.3***.

7.2.9 BARRIERS PREVENTING ACTIVE TRANSPORTATION

The respondents had to rate to which extent a list of barriers prevents them from cycling to the SU campus on a daily basis. The extent was rated by choosing a value from 1 to 5, where:

- 1 = do not prevent at all,
- 3 = prevent somewhat, and
- 5 = prevent very strongly.

Table 7.3 and ***Table 7.4*** show the results for the SU students and SU staff, respectively, along with an average rating per barrier.

For the students, “do not like walking or cycling irrespective of the distance” and “do not own or have access to a bicycle” received the lowest average ratings, whilst “travelling distance is too long” received the highest average rating. In general, the SU students residing in the southern suburbs / towns of /

Table 7.3: Barriers preventing active transportation among the surveyed SU students.

Barrier	Rating of the extent of the barrier to SU students					
	1	2	3	4	5	Avg.
do not own or have access to a bicycle	61	2	14	4	29	2.44
travelling distance is too long	5	3	8	6	88	4.54
safety concerns with regard to traffic incidents	17	7	18	20	47	3.67
security concerns with regard to mugging	13	10	21	23	42	3.65
route is too hilly / steep	19	15	27	14	37	3.31
too much / heavy baggage	16	9	21	27	36	3.53
few or no bicycle paths along the route	23	18	20	22	26	3.09
few or no pedestrian crossings along the route	33	15	28	16	17	2.72
no amenities, e.g. showers, secure bicycle sheds, locker facilities, at the final destination	20	14	16	17	42	3.43
do not like walking or cycling, irrespective of distance	49	15	20	3	22	2.39

Table 7.4: Barriers preventing active transportation among the surveyed SU staff.

Barrier	Rating of the extent of the barrier to SU staff					
	1	2	3	4	5	Avg.
do not own or have access to a bicycle	55	5	14	1	38	2.66
travelling distance is too long	13	4	13	8	75	4.13
safety concerns with regard to traffic incidents	10	4	14	14	71	4.17
security concerns with regard to mugging	15	10	21	17	50	3.68
route is too hilly / steep	21	10	18	18	46	3.51
too much / heavy baggage	20	13	15	22	43	3.49
few or no bicycle paths along the route	13	12	22	25	41	3.61
few or no pedestrian crossings along the route	24	22	26	18	23	2.95
no amenities, e.g. showers, secure bicycle sheds, locker facilities, at the final destination	16	9	19	21	51	3.71
do not like walking or cycling, irrespective of distance	33	21	14	9	36	2.95

to Stellenbosch do not cycle to campus because they do not want to, but because their long travelling distance does not make cycling a feasible mode of transport. Concerns for safety and security, steep topography, too much and / or heavy baggage as well as no amenities at the final destinations were also among the more frequently stated barriers.

The SU staff had a slightly higher average rating for "do not like walking or cycling irrespective of the distance", but "do not own or have access to a bicycle" also received a low average rating. The safety concerns with regard to traffic incidents received a slightly higher average rating than "travelling distance is too long", but the rating for the latter was still high, i.e. above 4 out of 5. The "no amenities, e.g. showers, secure bicycle sheds, locker facilities, at the final destination" barrier also received a somewhat higher average rating by the SU staff compared to the SU students. It is likely that this barrier received such high ratings because the respondents still assumed that they are expected to cycle all the way from home on their own bicycles. The need for a shower will not be as high when the cycling distances are limited to the average cycling distance of 5 km, and the need for secure bicycle parking will also fall away with the implementation of the proposed bicycle-sharing scheme.

As stated for the scholars, the identified barriers to cycling will be addressed in ***Section 9.4***.

8 ESTABLISHING SCHEME SIZE: RESULTS OF THE POTENTIAL-USER AND VEHICLE-TRIP-SAVING CALCULATIONS

The scheme *size* refers to the quantification of the bicycle-sharing demand / potential number of users. In this chapter, only the results of the potential-user and vehicle-trip-saving calculations that were discussed in ***Section 4.7.1*** for each of the road-user groups, are presented. The locations of the Drop-and-Go zone for the scholars and the Park-and-Ride for the SU students and staff, as well as the locations and distribution of the in-town docking stations, are proposed as part of ***Chapter 9***.

The calculations were performed to identify

1. the total number of potential bicycle-share users, and
2. the total number of potential vehicle trips that can be saved in the future

for each of the three high schools, as well as the SU-student and SU-staff road-user groups. At the end, these totals were multiplied by the proportions 0.75 and 0.5 to quantify the modifications M1 to M11, defined in ***Section 4.5.2.2***. Confidence intervals in line with a binomial distribution were given for the results, for the reason described in ***Section 4.7.1***.

8.1 SCHOLARS

Extracts of the potential-user calculations for the scholars are shown in ***Table 8.1***, ***Table 8.2*** and ***Table 8.3***, for the respective schools. The school staff was also surveyed, but the response rate was very low (so is the actual population) and their origins varied greatly. The response IDs of the responded school households (for which potential bicycle-share users were identified) are given in the table so that the details of their responses can be viewed in the spreadsheet containing all of the responses. This spreadsheet, along with the full calculation sheets, are provided on the attached CD. The number of potential users who were identified for each of the three schools are as follows:

- Bloemhof Girls' High School = 103,
- Paul Roos Gymnasium = 186, and
- Rhenish Girls' High = 69.

This results in a total of 358 potential bicycle-share users from the school learner population for the research case study.

The totals given in the tables after each subtraction represent a total number of respondents. It is only the final totals shown in red that are given as a share of the entire learner population of each respective school.

Since the potential-user calculation for the scholars was performed even before the research statement was defined, potential users were identified for all the Stellenbosch arterials. It could thus be determined that the learners incoming via the R44 corridor constitute 42.0% of the total potential users from all the directions – the highest proportion identified for a single direction. This is once the learners from the suburbs Brandwacht, Dalsig, Die Boord and Krigeville have been excluded. Whilst the learners from these suburbs are potential cyclists, they are not potential users of the proposed bicycle-sharing scheme, as they reside too close to the schools.

Table 8.1: Extract of the potential-user calculation for Bloemhof Girls' High.

Trip Origins	No. of respondents	% of total respondents	Minus hostel		Minus other modes		Minus *en route*		Response IDs	Minus primary school trips		Total learners
De Zalze	12	5.2		12	**2**	10	**4**	6	6005, 6024, 6082, 6158, 6599, 5976	**3**	3	
Jamestown	2	0.9		2		2	**2**	0			0	
Paradyskloof	20	8.6		20		20	**7**	13	5571, 5985, 5988, 6060, 6102, 6124, 6139, 6155, 6753, 5688, 6062, 6256, 6361	**2**	11	
Gordon's Bay	1	0.4		1	**1**	0		0			0	
Hermanus	1	0.4	**1**	0		0		0			0	
Kleinmond	1	0.4	**1**	0		0		0			0	
Somerset West	47	20.2	**8**	39	**16**	23	**6**	17	6002, 6015, 6037, 6111, 5716, 6011, 6070, 6083, 6162, 6166, 6175, 6212, 6221, 6613, 5719		17	
Strand	9	3.9	**2**	7	**3**	4	**1**	3	6055, 6239, 5710		3	
Total	93 (out of 233)			81		59		39			34	**103** (out of 709)

Table 8.2: Extract of the potential-user calculation for Paul Roos Gymnasium.

Trip Origins	No. of respondents	% of total respondents	Minus hostel		Minus other modes		Minus *en route*		Response IDs	Minus primary school trips		Total learners
De Zalze	20	5.2	**1**	19	**1**	18	**3**	15	5733, 6315, 5670, 5734, 5754, 5798, 5976, 6247, 6274, 6363, 5743	**3**	12	
Jamestown	1	0.3	**1**	0		0		0			0	
Paradyskloof	31	8.0		31	**6**	25	**6**	19	5623, 5656, 5688, 5764, 5789, 5819, 5868, 5896, 5965, 6062, 6092, 6256, 6360, 6361, 5793, 5856, 6139, 6507	**5**	14	
Betty's Bay	1	0.3	**1**	0		0		0			0	
Gordon's Bay	4	1.0	**1**	3	**3**	0		0			0	
Hermanus	2	0.5	**2**	0		0		0			0	
Somerset West	83	21.4	**6**	77	**37**	40	**14**	26	5653, 5692, 5719, 5933, 6109, 6439, 5642, 5681, 5687, 5769, 5776, 5831, 5847, 5961, 6337, 6412, 5716, 6152, 6166, 6613	**1**	25	
Strand	19	4.9		19	**6**	13	**4**	9	5872, 6184, 5710, 5749, 5837, 5698		9	
Total	161 (out of 388)			149		96		69			60	**186** (out of 1200)

Table 8.3: Extract of the potential-user calculation for Rhenish Girls' High.

Trip Origins	No. of respondents	% of total respondents	Minus hostel		Minus other modes		Minus *en route*		Response IDs	Minus primary school trips		Total learners
De Zalze	2	1.4		2		2	**2**	0			0	
Jamestown	3	2.1		3	**1**	2	**1**	1	6308	**1**	0	
Paradyskloof	10	7.1	**1**	9	**2**	7	**2**	5	6357, 6507, 6688, 6803	**1**	4	
Technopark	1	0.7		1		1		1	6471		1	
Gordon's Bay	2	1.4		2	**2**	0		0			0	
Hermanus	1	0.7	**1**	0		0		0			0	
Sir Lowry's	1	0.7		1		1		1	6494		1	
Somerset West	26	18.4	**3**	23	**16**	7	**2**	5	6476, 6501, 6540, 6543, 6584		5	
Strand	5	3.5		5	**2**	3		3	6477, 6554, 6589		3	
	51 (out of 141)			46		23		16			14	**69** (out of 691)

Table 8.4 reveals the potential motorised-vehicle-trip savings per school, as well as the total for all three schools combined. Due to the different sample sizes of the three schools, one respondent represents 3.04 learners of the entire school population at Bloemhof Girls' High, 3.09 learners at Paul Roos Gymnasium and 4.9 learners at Rhenish Girls' High School. When subtracting for siblings who share a vehicle trip, but attend different schools, the total number of remaining vehicle trips varies depending on from which school the subtraction is made. For example, for a brother and sister attending Paul Roos Gymnasium and Rhenish Girls' High, respectively, 3 vehicle trips have been counted for Paul Roos Gymnasium and 5 for Rhenish Girls' High. This issue was resolved by subtracting the average of the two values (i.e. 4).

The information from the survey responses that was required to determine the private-motor-vehicle-trip savings is also provided on the attached CD. A total number of 266 vehicle-trip savings were identified for the scholars.

Table 8.4: Results of the calculation for the potential private-motor-vehicle-trip savings.

Total number of vehicle trips for Bloemhof Girls' High School*	98
Total number of vehicle trips for Paul Roos Gymnasium*	144
Total number of vehicle trips for Rhenish Girls' High School*	65
Total number of vehicle trips*	**307**
Subtraction for siblings at different schools	- 41
Total number of vehicle trips	**266**

*with subtractions for hostel / boarding school, other modes of transportation, *en route* trips, and primary school siblings already performed.

95th percentile confidence levels (binomial distribution) were placed on the following results:

1. the identified total number of scholars per school (i.e. the total number of learners as a proportion of the entire learner population in the school) residing in the southern suburbs / towns to / of Stellenbosch;
2. the identified total number of potential bicycle-share users per school; and
3. the identified total number of potential motorised vehicle trips that can be saved in the future.

The resultant confidence intervals are shown in ***Table 8.5***. The 'result' numbers refer to those that were just listed.

Table 8.5: Confidence intervals per school for the number of learners residing in the southern suburbs / towns of / to Stellenbosch, as well as the potential-user and vehicle-trip-savings calculations.

Result	School	Confidence interval		
		Lower value	Mid-value	Upper value
1 (in persons)	Bloemhof Girls' High	257	283	309
	Paul Roos Gymnasium	464	498	532
	Rhenish Girls' High	225	250	276
2 (in persons)	Bloemhof Girls' High	85	103	123
	Paul Roos Gymnasium	162	186	212
	Rhenish Girls' High	54	69	84
3 (in veh)	Bloemhof Girls' High	81	98	118
	Paul Roos Gymnasium	123	144	168
	Rhenish Girls' High	51	65	82

The mid-value was used for all cost- and benefit analyses performed for the bicycle-sharing alternative, because the various modifications and scenarios indirectly test at least the lower confidence levels.

In ***Table 8.6*** the 0.75 and 0.5 proportions of the identified total potential bicycle-share users and vehicle-trip savings for the schools, required for testing the scenarios comprising modifications M1, M2, M7 and M8, are presented.

Table 8.6: 0.75 and 0.5 proportions of the identified total potential bicycle-share users and vehicle-trip savings for the schools

Result	School	0.75 proportion	0.5 proportion
Total potential users (in persons)	Bloemhof Girls' High	269	179
	Paul Roos Gymnasium		
	Rhenish Girls' High		
Total vehicle-trip savings (in veh)	Bloemhof Girls' High	200	133
	Paul Roos Gymnasium		
	Rhenish Girls' High		

8.2 STELLENBOSCH UNIVERSITY STUDENTS AND STAFF

As for the summaries of the travel survey results, the results for the potential-user and private-vehicle-trip-savings calculations for the SU students and staff are provided in the same subsection here, but the results are presented separately for each of the two road-user groups. The evaluation of the total potential bicycle-share users for the SU-student and SU-staff road-user group was a lot less complex than for the scholars, because all the respondents reside in the southern suburbs / towns of / to Stellenbosch and thus no pre-calculation had to be performed to determine the number of R44-corridor trip makers. After filtering out the respondents who met the non-potential user criteria (except for the lift-club criteria), 61 of the SU-student respondents and 82 of the SU-staff respondents were identified as potential users. The response IDs for these respondents are given in ***Table G.1*** in ***Appendix G***. The spreadsheet containing all the SU survey responses is provided on the attached CD; the full responses of the respondents named in ***Table G.1*** can thus be found there.

16 of the identified SU-student potential users are in a lift club with one other person. Assuming that both members of the lift club responded to the survey, 8 was subtracted from 61 to obtain the number of potential vehicle-trip savings. For the SU staff, 11 of the 82 identified potential users are in a lift club with one other person. These numbers of potential users and potential vehicle-trip savings for each of the two road-user groups were then given as a proportion of the total number of respondents per road-user group, and multiplied by the total SU-student and SU-staff population residing in the southern suburbs / towns of / to Stellenbosch to obtain the total number of potential users and potential number of vehicle trips that could be removed from the modelled network in the future. The results are shown with confidence intervals (binomial distribution) in ***Table 8.7***. The mid-value is the result that was calculated. The 0.75 and 0.5 proportions of all the mid-value results are also given in the table.

Table 8.7: The total number of potential bicycle-share users and the total number of potential vehicle-trip savings for the SU-student and SU-staff road user groups (given with 95th percentile confidence intervals).

Result	Confidence interval	SU students			SU staff		
		Confidence value	0.75	0.5	Confidence value	0.75	0.5
Total potential bicycle-share users	Lower value	460			222		
	Mid-value	490	368	245	241	181	121
	Upper value	520			259		
Total potential vehicle-trip savings	Lower value	395			206		
	Mid-value	425	319	213	225	169	113
	Upper value	455			243		

9 CONTEXT-SENSITIVE CONCEPTUAL DESIGN OF THE PROPOSED BICYCLE-SHARING SCHEME FOR STELLENBOSCH

In this chapter, reference is repeatedly made to previous ***Chapter 2*** where much of the input to the context-sensitive conceptual design of the proposed bicycle-sharing scheme for Stellenbosch has been reasoned and conversed. Of course, international bicycle-sharing companies that specialise in the design and implementation of bicycle-sharing systems (specific to the needs of the client) exist, and some were contacted, but none were (understandably) able to provide assistance with the design of a theoretical scheme or the costs thereof. Taking an off-the-shelf design that is not context sensitive was out of the question. That is why the author came up with her own conceptual design. This design only goes as far as was necessitated to evaluate the relevant costs and benefits of such a scheme. In some cases, details are given nonetheless, but the objective of this design was not to be set on all the design specifications from the start; it was of greater essence to explore numerous design possibilities, and ultimately only propose a project solution. This solution, which is conversed in this chapter, deviates from the typical design described in the literature review for reasons that are given in the text. This chapter, moreover, discusses how the barriers to cycling (identified in ***Chapter 7***) are to be addressed and how they were incorporated in the conceptual design.

The vision of the design phase was to come up with a state-of-the-art bicycle-sharing solution for Stellenbosch that is cost-effective, but yet does not sacrifice quality. It was unspoken, but nonetheless well understood, that the implementation of such a solution has to succeed at its first attempt, and be designed so that it becomes an attractive alternative mode of transportation in the current car-centric environment. The deployment of the scheme demands road users to change long-existing habits, and it is so important that those who make the shift are not presented with a sub-standard design, or even worse: system failure, as this will drive people away from the idea perhaps not for forever, but at least for a few years to come, and it will take a lot of effort to convince people why the second attempt is better than the first.

9.1 SERVICE AREA AND PHASING

This research project evaluates the economic viability of a theoretical bicycle-sharing scheme for school and university destined commuter traffic for a study area in the town of Stellenbosch, but the intention was to finally extrapolate the findings to all the commuter traffic destined to Stellenbosch. In the bigger picture, the service area of the scheme is thus the wider town of Stellenbosch, but in this research project, it is limited to the defined study area.

The scheme is to be implemented in three phases, as described and argued in ***Section 1.3.3***. To recap, the proposed phases are as follows:

- phase 1 = bicycle-sharing for scholars,
- phase 2 = add bicycle-sharing for SU students and staff, and
- phase 3 = add bicycle-sharing for general commuters.

Only the first two phases were evaluated in this research project, because it is believed that these phases need to generate and accelerate visible success before phase 3 is carried out. The SU staff were parted from the SU students in the CBA though, for it was assumed that they may fall more into the group of the general commuters, i.e. they will take longer to become fond of the idea of cycling to work for at least a part of their journey. Casual riders and tourists will form part of the system from the start (see ***Section 9.5***), but the extent to which this is so will increase as the other phases are implemented.

9.2 SYSTEM PARAMETERS

9.2.1 MINIMUM SYSTEM SIZE

It was not in the scope of this research project to establish the exact size of the bicycle-sharing scheme; only the maximum number of potential users, and modifications to this number, were calculated per road-user group and tested in a number of scenarios in terms of costs and benefits. Due to the relatively high capital costs of the scheme (see ***Chapter 10***), it was obvious that the economies-of-scale concept would apply: the more users, the more cost-effective the scheme will become per bicycle (ignoring the benefits to society and the growth of these benefits with an increase in bicycle-share users). In ***Chapter 13***, it is shown which of the investigated scenarios are economically viable and which are not.

9.2.2 STATION DENSITY

In a bicycle-sharing system for commuters, the station density of the system is far less critical to its success than in a scheme for the general population. This is because each user will cycle predominantly between a set Drop-and-Go zone or Park-and-Ride and a known in-town docking station; fewer trips are anticipated to be made between the in-town docking stations. As will be described in more detail in ***Section 9.5.1***, the bicycles that will be cycled into Stellenbosch by the commuters are to be made available to casual users who can utilise the bicycles during office hours, i.e. before the commuters cycle them back to the Park-and-Rides. This is only the case for the bicycles that are to be cycled to campus, i.e. not to the schools. It is for these casual riders that station density plays more of a significant role. The system should provide a reasonable station density so that the casual users (predominantly SU students) can easily access a station and cycle to a station that is close to their destination. The site locations proposed in ***Section 9.3.3.2*** for the campus stations are all in the vicinity of at least one main SU building and not more than approximately 1 km away from the nearest station. This distance between the stations is slightly higher than the typical 300 m found in the literature review, but believed to be acceptable. An additional docking station is proposed to be deployed near the Eikestad Mall to provide for the daily errands of the potential casual riders, and make the scheme more attractive to them a result.

All the above applies to phase 1 and 2 of the implementation plan. Many more docking stations will be required when phase 3 – bicycle-sharing for the general commuter – is eventually carried out. The destinations of these general commuters will cover a wider spectrum, and to accommodate them all, a greater station density in Stellenbosch will automatically come about.

9.2.3 NUMBER OF STATIONS, BICYCLES AND DOCKS

A total of 10 bicycle docking stations are proposed for the case study of this research project. The site locations of these stations are given in the subsequent subsection. Four of these stations are to service the scholars, and the remaining six stations are to be implemented for use by the SU students and staff. As said for the minimum system size, various options with regard to the number of bicycles in the system were tested (based on the total number of potential users that were calculated and for which the in-town destinations are known); no single number was specified.

Alta Planning and Design, a North-American company that has prepared bicycle-share feasibility studies and business plans for most of the cities in the United States with a scheme in place, stated (2013) that operators have tested dock ratios ranging from 1.5 to 2.0 docks per bicycle. A dock ratio of only 1.2 was, however, applied for the in-town docking stations in the cost analysis of this research project due to the directional nature of the expected trips, i.e. the everyday origin and destination of the bicycle-share users will be known for the scholars and with high certainty for the SU students and staff in terms of the destination.

9.3 SITING CONSIDERATIONS

The site locations for the docking stations (Drop-and-Go zones and Park-and-Rides as well as in-town stations) were identified after considering a number of input parameters. These were listed in ***Section 4.7.1***, and are elaborated on here before the locations of the stations are presented. The locations that are shown are intended to be general; they have not at this stage considered public input, land ownership and right-of-way, the interest of adjacent land owners, or the physical constraints of each site.

9.3.1 INPUT PARAMETERS

9.3.1.1 ACCEPTABLE CYCLING DISTANCE

In the literature review, reference was made to Nelson *et al*. (2008) who state that distances within about 4 km are achievable by adolescent cyclists. This was selected as the maximum acceptable cycling distance for the scholars, i.e. the maximum distance the Drop-and-Go zone was allowed to be located from the schools. For the SU students and staff this distance was set to 5 km – the mode and median acceptable cycling distance indicated by the SU respondents of the survey.

9.3.1.2 TOPOGRAPHY

The literature review revealed that cyclists dislike gradients of more than +4% (Midgley, 2011), and that a 10% increase in hilliness is coupled with a 10% to 15% drop in the number of persons cycling to work (Parkin *et al*., 2007). As such, the Drop-and-Go zone and Park-and-Ride were sited so that the cyclists encounter a primarily flat topography, with a maximum grade of 4%, *en route* either into or out of town. The elevations along the routes were retrieved from Google Earth. In the core of Stellenbosch itself, the topography is flat and thus did not form part of the station-location criteria.

9.3.1.3 TRAFFIC CONGESTION HOTSPOTS

The traffic congestion hotspots were identified from the KMZ output files of the probe data that were viewed in Google Earth. These hotspots had to be identified, so that it can be ensured, where possible, that the Drop-and-Go and Park-and-Ride are sited upstream of these areas (to avoid congestion). Hotspots refer either to roadway segments along the R44 corridor where the traffic conditions are particularly adverse relative to the rest of the route, i.e. lower average travel speed, higher average travel time and higher average travel time ratio, or an individual point on the route from where the extent of the traffic congestion is severe uninterruptedly until (and beyond) the R44 / Van Reede intersection.

The per-segment probe data results are provided on the attached CD.

9.3.1.4 VACANT LAND

For the purpose of this case study, vacant land was recognised as any unbuilt area as seen from Google Earth imageries; as mentioned above, land ownership was disregarded here.

9.3.1.5 EXISTING BICYCLE NETWORK

The state of the existing bicycle network and facilities (as of 2015) was not encompassed in the station-location criteria, but the plans of the Cycling Plan and the related priorities were closely scrutinised instead (see ***Section 9.4***).

9.3.1.6 INTERSECTIONS AND CROSSINGS

Same as for ***Section 9.3.1.5***.

9.3.1.7 KEY DESTINATIONS

The general destinations, namely the three respective schools and the SU campus, were easy to identify. There is not more to it for the schools, but more than one docking station had to be located on the SU campus. These locations were pinpointed, along with the vacant land criteria, from the travel survey responses of the potential users who indicated their field of study / work, i.e. the department or office building that they are destined to every day. The Eikestad Mall, named in Section 9.1, is an attraction for the SU students that offers amongst other things grocery stores and a health club, and hence is a key destination to the casual riders of the scheme.

9.3.2 DROP-AND-GO AND PARK-AND-RIDE LOCATIONS

9.3.2.1 DROP-AND-GO ZONE LOCATION FOR SCHOLARS

The point of departure for defining the location of the Drop-and-Go zone for the scholars was to move backwards an average distance of 4 km (the maximum acceptable cycling distance for scholars) along the route from the three schools. The 4km-point is located between the entrance to Technopark and the De Zalze estate. Looking at the topography, a trip made from this point towards the schools starts at an elevation of 92 m, increases to 140 m (grade of 4.18%) and then drops again to 99 m at the end of the R44 corridor (R44 / Van Reede intersection), from whereon forth relatively flat terrain is encountered. The reverse, of course, holds for the return trip. The traffic conditions vary along this route with an average travel time ratio (AM peak vs. free flow from probe data) of 2.5 until 150 m before Blaauwklippen Rd that then decreases to 1.5 until Paradyskloof Rd. From there the average travel time ratio increases for most of the route, and for the approximately last 450 m it is 4.9 and higher, reaching a maximum of 9.55. Vacant land is found before and after Paradyskloof. Since the implementation of the bicycle-sharing scheme is expecting learners to change their habits and give up parts of their comfort (e.g. some inactive individuals are asked to become active cyclists), it was decided, as stated above for the input parameters, to avoid hilly terrain where possible. The unbuilt land at Trumali St was eventually defined as the location for the Drop-and-Go zone for the scholars (see ***Figure 9.1***). The cycling distance to / from the schools from / to here is short and the topography reasonably flat (2.1 % downhill to the end of the corridor and then an elevation varying between 99 m and 111 m for the rest of the route; opposite on the way home), but most importantly, the parents will still avoid the severe traffic congestion when dropping and picking up their children to / from this point. This route also forms part of the priorities of the Cycling Plan in terms of providing high-quality bicycle facilities, including bicycle-friendly improvements to the R44 / Van Reede intersection.

9.3.2.2 PARK-AND-RIDE LOCATION FOR SU STUDENTS AND STAFF

A similar approach as for the school learners was taken to define the Park-and-Ride location for the SU students and staff, except with the maximum cycling distance set to 5 km. The SU campus is, of course, situated further away from the R44 corridor than the schools are, so it made sense not to set the Park-and-Ride further back along this route than the Drop-and-Go zone for the schools. Since Trumali St is proposed to be occupied by the school learners, the next vacant area of land is at the entrance to the Die Boord residential area on the left-hand side of the R44 / Van Reede intersection when approaching from the south (see ***Figure 9.1***). This land is sited an average distance of 3.2 km from the SU campus, and is proposed as the location for the Park-and-Ride. Although this location still requires some traffic-congestion driving leading up until the R44 / Van Reede intersection, the level of the congestion is expected to be lower than it currently is once many of the school trips have been taken off the network.

9.3.3 IN-TOWN STATION LOCATIONS

9.3.3.1 DOCKING STATIONS AT THE SCHOOLS

Bicycle docking stations are proposed to be constructed at each of the schools to avoid a walking distance of longer than 100 m to and from school. In the cost analysis, the option for Bloemhof Girls' High and Rhenish Girl's High to share a docking station is considered, however (see ***Chapter 10***).

9.3.3.2 DOCKING STATIONS ON CAMPUS

Based on the location of the main campus buildings and the responses of the SU potential users regarding their field of study / work, four campus locations were singled out for the erection of bicycle docking stations. These are to be somewhere in the vicinity of:

1. the Sport Science Faculty,
2. Admin A,
3. the Neelsie Centre parking lot / the Economic and Management Sciences Faculty, and
4. the Engineering Faculty.

These locations are indicated in ***Figure 9.2***. They are a cycling distance of

1. 2.8 km,
2. 3.0 km,

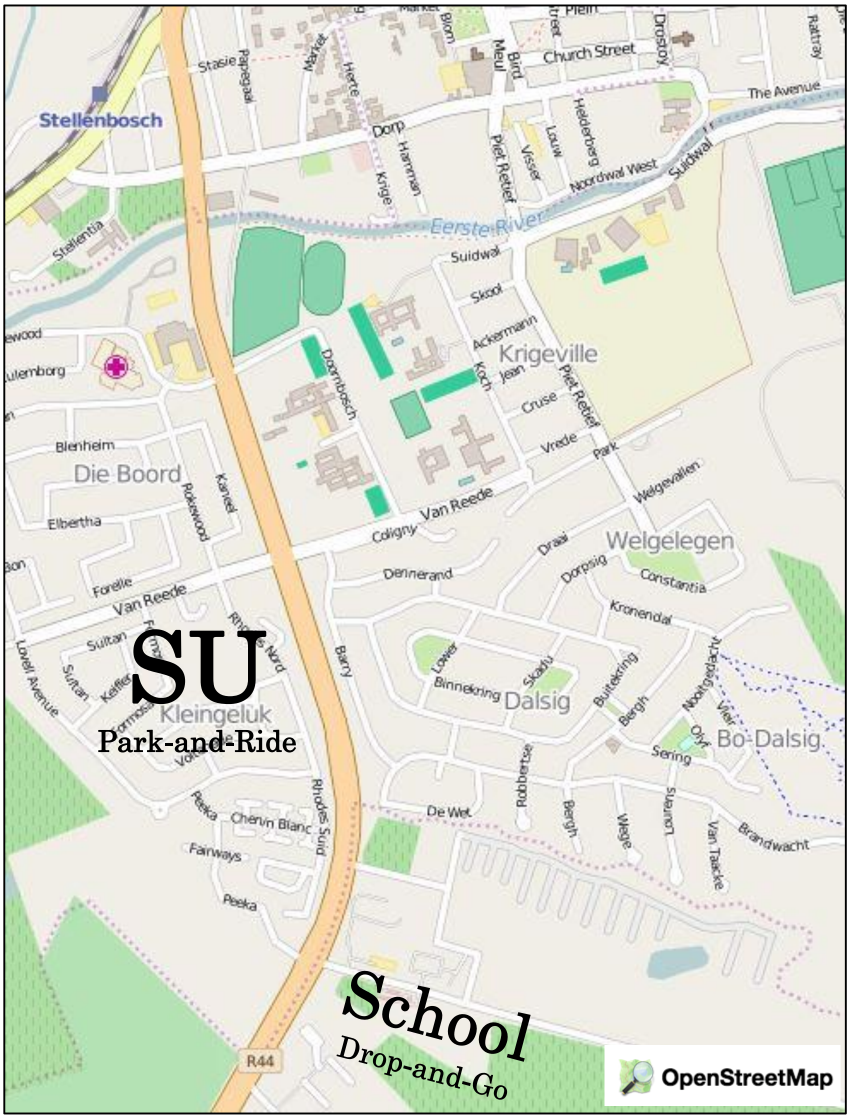


Figure 9.1: Proposed location of the Drop-and-Go zone for the school learners and location of the Park-and-Ride for the SU students and staff (Area 3 on map in ***Appendix A.1****).*

3. 3.2 km, and
4. 3.8 km

away from the Park-and-Ride, respectively.

A fifth in-town docking station is proposed to be built near the Eikestad Mall, as already stated.

Based on their field of study / work, the identified SU-student and SU-staff potential users were all allocated to one of the four campus docking stations. The results are shown in ***Table 9.1***. The 0.75 and 0.5 proportions of the total numbers were taken for the testing of the various scenarios.

9.4 ADDRESSING THE BARRIERS

In order for the bicycle-sharing scheme to be a success, the barriers to cycling revealed in the literature review, and especially those barriers identified by the survey participants, have to be addressed.

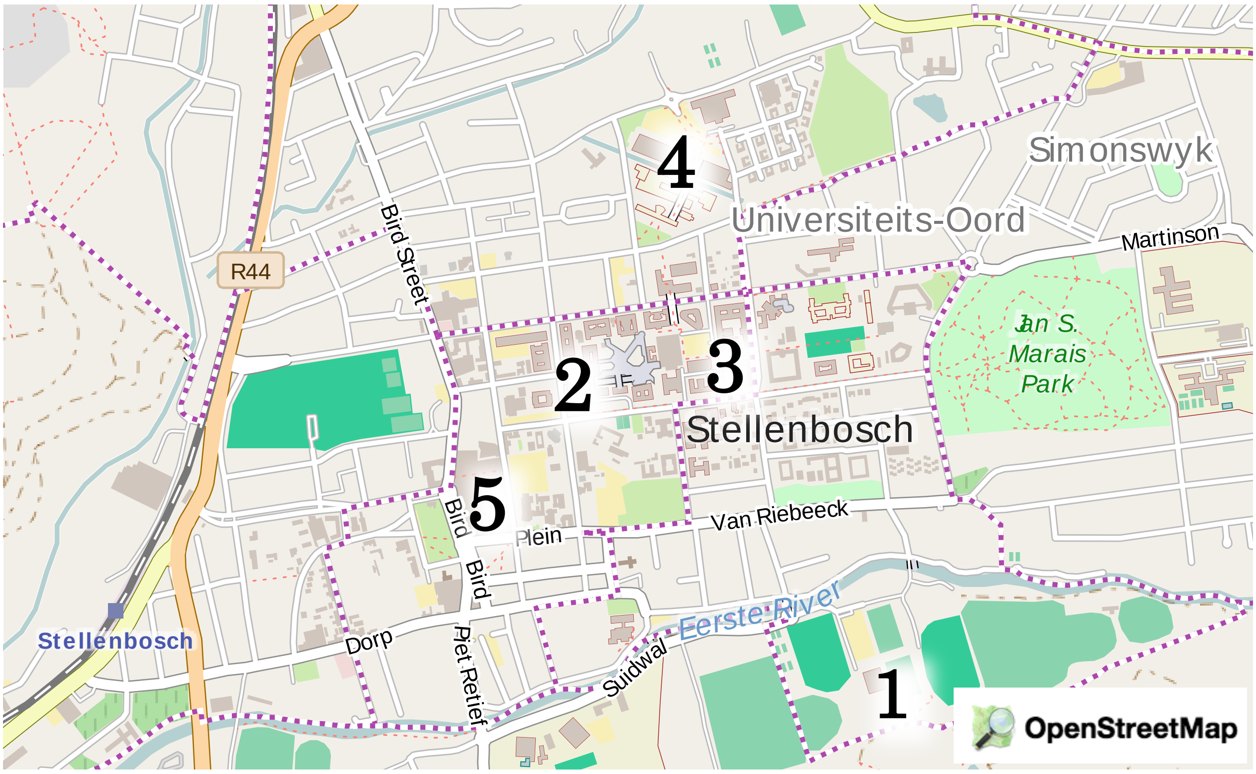


*Figure 9.2: Proposed location of the in-town campus docking stations (Area 4 on map in **Appendix A.1**).*

Table 9.1: Number of the SU-student and SU-staff potential users that will travel to each of the four campus docking stations on a daily basis.

Station no.	SU students		SU staff		SU students and staff	
	respondents	total	respondents	total	respondents	total
1	1	8	1	3	4	11
2	20	161	42	123	62	284
3	34	273	31	91	65	364
4	6	48	8	24	14	72

Measures that attend to these barriers (and hence were to be included in the design) are proposed and discussed in this section.

9.4.1 TRAVELLING DISTANCE TOO LONG

Travelling distance too long is what the proposed bicycle-sharing scheme for Stellenbosch in conjunction with a Drop-and-Go zone and a Park-and-Ride is all about - it is the motivating force and inspiration for implementing the scheme in the first place, and hence will no longer be a barrier to cycling work / school (at least for a part of the way).

9.4.2 SAFETY CONCERNS

In ***Section 2.4.1.7.1*** cycling was described as a benign activity that often takes place in dangerous environments. Garrard (2008) said that “the focus needs to be on promoting safe walking and cycling by reducing traffic danger from people, not removing people from the hazardous environment we have created." Cyclists, alongside pedestrians, are the most vulnerable road-user group; designing a safe system away from motorised traffic was thus of utmost importance. It should be noted though that absolute safety can never be guaranteed; it can only be sought to minimise the risk exposure of cyclists to bicycle-related accidents. The safety of the community as a whole (e.g. zero fatalities), and the promotion of safe cycling, are aspirational goals shared with Sustainable Stellenbosch and the Cycling Plan (prepared for the municipality).

It has been alluded to earlier in numerous sections of this document that it is assumed that the objectives of the Cycling Plan to improve bicycle network coverage in Stellenbosch, will have been achieved to a large extent before the proposed bicycle-sharing scheme is deployed. The Cycling Plan was introduced in ***Section 1.2.2*** and is discussed in more detail in ***Section 9.4.6***. With the intention of segregation between cyclists and motorists on the high-class roads, the focus of road safety shifts to the traffic crossings – the conflict points. The discussion on bicycle-friendly traffic crossings is included in ***Section 9.4.6***. As a general comment though, this safety issue could be addressed by marking out specific bicycle routes that comprise as few conflict points as possible. The notion behind these routes that are to be used by everyone (not only bicycle-share users, but all cyclists) is that while the budget of the municipality does not allow for major cycling-friendly enhancements to be made at all the intersections at once, instead of performing minor improvements at all the intersections, a handful should be prioritised and extensive safety measures should be implemented there. The list of suggested safety measures included the following:

- priority rules / right of way to cyclists,
- pedestrian countdown timers (pedestrians and cyclists are more likely to wait their turn), and
- wider paved queuing areas for cyclists and painted stand-back lines (see ***Section 2.4.2.4***, where bicycle boxes were described).

For the shared road spaces (cyclists in the general roadway or on dedicated bicycle lanes), traffic calming measures (that deliberately slow traffic) are suggested in the Cycling Plan, which are also elaborated on in ***Section 9.4.6***.

The Power Model (Nilsson, 1981) states that there is an exponential relationship between the speed of traffic and the severity of injuries during a collision. Due to the vulnerability of cyclists, they should only be permitted to be exposed to motorised traffic when the speed of this traffic is constrained. The Road Safety Authority of Ireland launched the Mess-and-Crash campaign to draw attention to the consequences of speeding: "every time human error causes a road collision it is the speed of the vehicles which determines the outcome – whether someone lives or dies, or is maimed for life", i.e. the faster the speed, the bigger the mess. Sweden's Vision Zero road safety approach identifies the importance of protecting cyclists from traffic speeds exceeding 30 km/h (Jacobsen & Rutter, 2012). The Dutch Design Manual for Bicycle Traffic adds to the 30 km/h speed limit that for bicycles to operate in mixed traffic, the traffic volume should also be less than 5,000 vehicles per day or less, and the road should have no lane markings, including no centreline. In ***Section 2.4.2.4***, a figure (***Figure 2.9***) was shown from Transport Scotland (2011) from which the required type of bicycle facility can be determined from traffic volumes and speed.

The roads in Stellenbosch have a default speed limit of 60 km/h unless specified otherwise. This speed limit is, without doubt, too high for the local streets and most of the town collector roads, and it is imperative that this matter is addressed, even if the average travel speeds are very low in the AM and PM peak – the time when the bicycle-share users are most likely to cycle. According to the Cycling Plan, general traffic speed reductions in urban areas of South Africa are currently being pursued by the Minister of Transport.

Although children have been excluded from the proposed bicycle-sharing scheme (for the reasons given in ***Section 1.3.3***), adolescents are still at a greater risk in the road environment than adults, because their attention is easily lost, they have limited traffic experience, are small in stature, and find it difficult to accurately judge speed. The Cycling Plan describes the action that needs to be taken at the schools: "scholar precinct traffic management plans are needed, professionally prepared, with non-motorised access as the primary focus, with the full support of schools and active involvement of governing bodies, parent committees and the municipality. Strict parking control, dead-slow speeds, strict enforcement against illegal activities and strong communication programmes are all essential components of developing a safe and effective approach".

It is suggested that education in road safety and on-road behaviour, especially from the perspective of cyclists, is to be presented at the schools before the scheme is implemented. If the cycling modal share is to increase, it is crucial (to the cyclists' own benefits) that cyclists are not guilty of bad behaviour on the road and that they abide by the rules of the road. As the Cycling Plan acknowledges: "many drivers have a poor understanding of the full range of road rules, including those relating to cyclists with some even still regarding cyclists as less entitled to use of road space". Furthermore, safety guidelines should be published in the media from two angles: that of cyclists and that of motorists. The same safety guidelines should be uploaded onto the scheme's social media accounts (incl. its website) and distributed during registration.

The bicycles are proposed to be lime green in colour to give them a perceptible appearance. This is likely to reduce the number of "looked-but-did-not-see" incidents. In addition, as was made known in the write-up of the literature review, it was found in Brisbane that the cyclists on public bicycles received more consideration from motorists than the cyclists on private bicycles. This was believed to be owing to the fact that a public bicycle was still somewhat of a rare sight in the city. Furthermore, the safety in numbers theory was found to apply to cycling: as the number of cyclists in the population increases, the perception motorists have of cyclists increases.

In conclusion, Buis *et al.* (2000) (see ***Section 2.4.1.7.5***) found all three of the main safety measures discussed here, namely segregated bicycle paths, priority for cyclists at traffic intersections as well as speed restrictions, to result in high BCRs.

9.4.3 PERSONAL SECURITY CONCERNS

Personal security refers to the state of being free from the threat of deliberate criminal activity – an activity that is giving rise to immense general concern in South Africa, i.e. not only as a barrier to the development of cycling. The Cycling Plan states that improved visible policing, law enforcement and security programmes are no doubt vital components of an overall successful cycling system.

It is believed that the safety-in-numbers concept also pertains to personal security in that vigilance is enhanced and thus the opportunity of an attack reduced (there are plenty of potential witnesses on the road network at the time of commute). On that account, the recommended bicycle routes also address the personal security barrier. These routes are much like the Green Routes already existent on the SU campus; in many places these routes may overlap.

The concerns for personal security may be mitigated by the fact that the fear of bicycle theft will not lie with the bicycle-share user; it is proposed that in the case where an incident of *en-route*-mugging can be proven, the cost is carried by the operator of the scheme (and its insurance). Once a bicycle has been docked at a destination, the responsibility for the safe-keeping of that bicycle also shifts from the user back to the operator.

9.4.4 TOPOGRAPHY AND CLIMATE

The topography issue was already addressed in ***Section 9.3*** : no routes are to have steep grades.

The meteorological factor was not accounted for in the conceptual design of the scheme, as the Mediterranean climate in the Western Cape and its average monthly temperatures, suggest acceptable overall cycling conditions all-year-round. Of the 365 days between October 2014 and September 2015, there were 40 days with a temperature high above 28 °C (only 1 day with a temperature above 35 °C), and 59 rain days (of which 32 days had a rainfall of less than 4 mm for the day) according to Accuweather. The rain rates could unfortunately not be determined from this data, because the durations of the rainfall periods were not given. Weather.sun.ac.za does, however, report on rain rates. The average rain rates for the past 5 years were all recorded to be below 1 mm/h for the university's five weather stations. This corresponds to a rain intensity classification *light rain* (rain rate < 2.5 mm/h). In terms of the rate, it should be noted that most of the cycling will be done in the early mornings and late afternoons, when temperatures are not at their highest.

The Accuweather and Weather.sun.ac.za data is provided on the attached CD.

9.4.5 TOO MUCH AND / OR HEAVY BAGGAGE

As found from the distributed travel surveys, *too much and / or heavy baggage* is a hindrance to cycling for many of the respondents. The baggage refers to, for example, schoolbooks, textbooks, personal computers and sports / extra-curricular gear / equipment. This barrier has not been managed by the schools in the past due to the assumption that learners are being driven to school. The schools are now taking action though to move towards using electronic tablets in the classrooms, most probably not to increase the bicycle modal share, but that is beside the point. At Rhenish Girls' High, for example, all grade 8s are required to bring a tablet to school next year. This is a step in the right direction, but as seen for the SU students and staff, the learners will continue to have baggage, and for this reason front carriers as well as bicycle trailers have been included as part of the design (see ***Section 9.6.2***).

9.4.6 FEW OR NO BICYCLE PATHS AND BICYCLE-FRIENDLY CROSSINGS

Few or no bicycle paths and bicycle-friendly crossings is a barrier directly linked to concerns of safety; in the absence of these facilities, actual and perceived safety is low, and it is assumed that this is the underlying barrier to cycling. This subsection thus goes hand-in-hand with ***Section 9.4.2***.

Of all the countries with successful bicycle-sharing systems, many already had a high quality and quantity of bicycle facilities, as well as a significant modal split for bicycles, in place in the urban areas before the implementation of bicycle-sharing. Whilst this cannot yet be said about Stellenbosch, the Cycling Plan envisions extensive network coverage to develop within the next 1 to 15 years. **It is the interventions suggested in the Cycling Plan on which this context-sensitive conceptual design is built.**

Extracts from the Cycling Plan have been puzzled together in this subsection to summarise what the plan proposes in terms of cycleways and intersections. Supplementary information and comments are given in between.

Table 9.2 shows the guideline applied in the Cycling Plan for the development of cycleways.

Table 9.2: Guideline applied in the Cycling Plan for cycleway development in Stellenbosch.

Road class	Function	Typical appropriate cycleway class	Description
Principal arterial	Mobility	Class 1	Separate cycleway (outside the road reserve)
Major arterial			
Minor arterial		Class 2	Cycleway connected to road (hard infrastructure separation)
Collectors	Accessibility	Class 3 (and class 2)	In roadways – separation by paint
Local street		Class 4	Shared space on street

Figures 9.3 and ***9.4*** show the typical cycleway provision on *a main urban arterial / district distributor and applies to the R44 and the R310 Adam Tas through Stellenbosch. In both examples, Option 1 shows a 1.5 to 1.8m cycle lane flanking the road carriageways in each direction, ideally with at least some partial (broken) separation.* A *1.8 m width is* an *adequate width to enable cycles to overtake without veering into the general carriageway. Option 2 indicates cycle provision accommodated via a 3 m general-use pathway on each side of the road, separated from the road by a green zone divider.* ***Figure 9.5*** *shows cross section options for urban streets and local collectors indicating a class 3 cycle path on the left-hand side of the general carriageway. A separated mixed use 3 m pathway as in Option 2 is also an applicable option for these road classes.* ***Figure 9.6*** *indicates a cross section for residential streets. In the South African context, most residential streets do not have a separated walkway, and* cyclists *and* pedestrians *must use the general roadway. This situation further strengthens the case and the urgency for dropping vehicles speeds on residential streets.*

A detailed survey of each area and proposed road links for cycling in Stellenbosch *was conducted. This led to the development of primary and secondary routes and their corresponding network. Links were assessed, and a cycleway type* was *recommended* for both the short term and the long term. *An intervention was recorded for each link on the proposed cycle network. These are provided as suggested treatments and should not be regarded as firm recommendations. Referencing of the interventions was captured in a route cross section image marked up with an overlay as a mock-up of the recommended treatment.*

In ***Appendix H.1***, ***Table H.1***, the interventions, cycleway class and priority recommended for those sections of road that form part of the study area are shown. All sections belong to a specific zone and are identified by a cycle route node. The full catalogue of route cross sections for each zone of the town is provided on the attached CD. *Many of the links have more than one suggested treatment to improve cycling access. Generally these are intended to be implemented across different time periods, with a short term intervention and a longer term. Importantly then, the prioritisation of treatments is key.* The zones pertinent to this research project refer to the following areas of Stellenbosch:

- Zone A = arterial routes through the town,
- Zone F = Die Boord, and

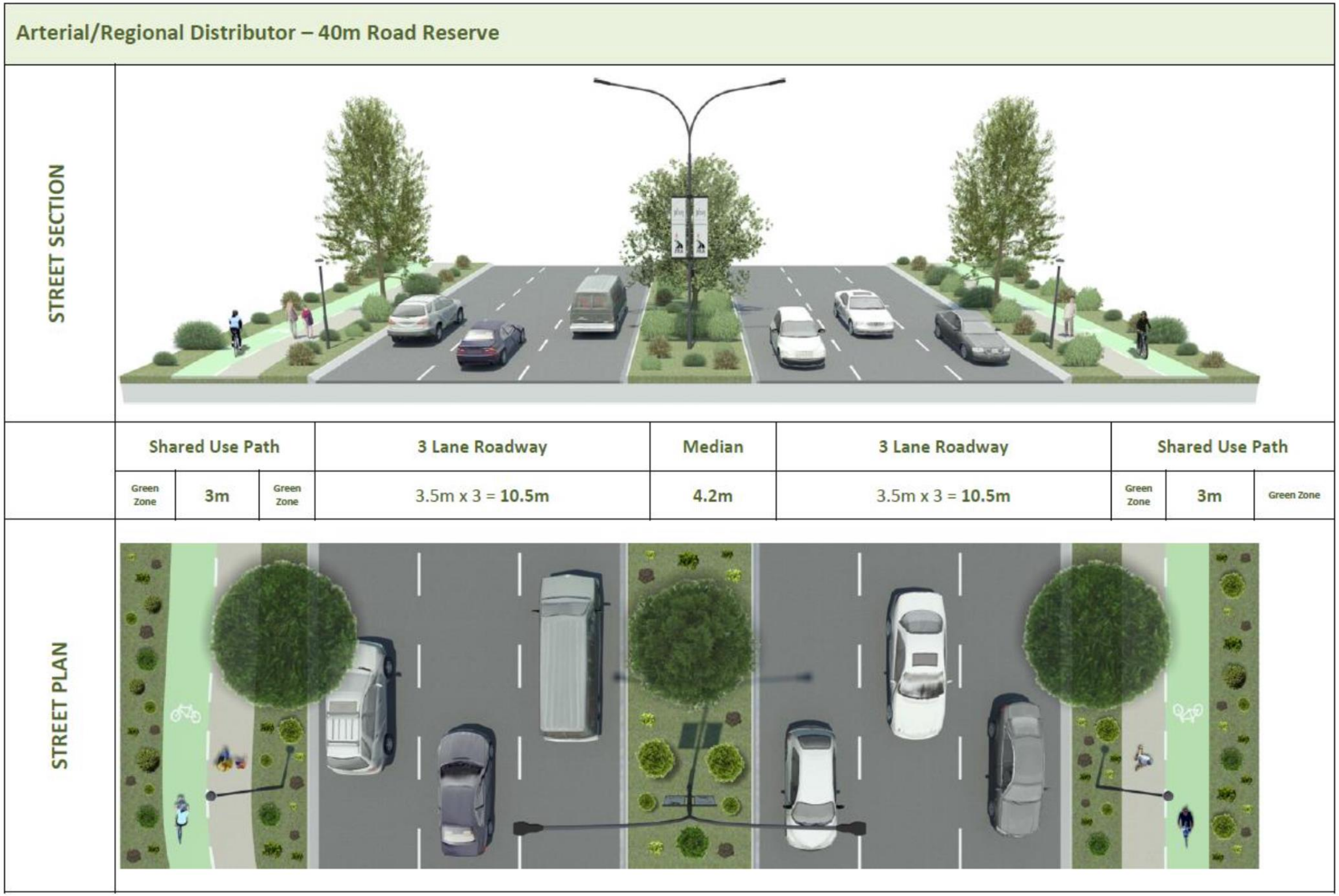


Figure 9.3: Cycleway provision on major arterial route as shown in the Cycling Plan (Source: Transport Futures, 2015).

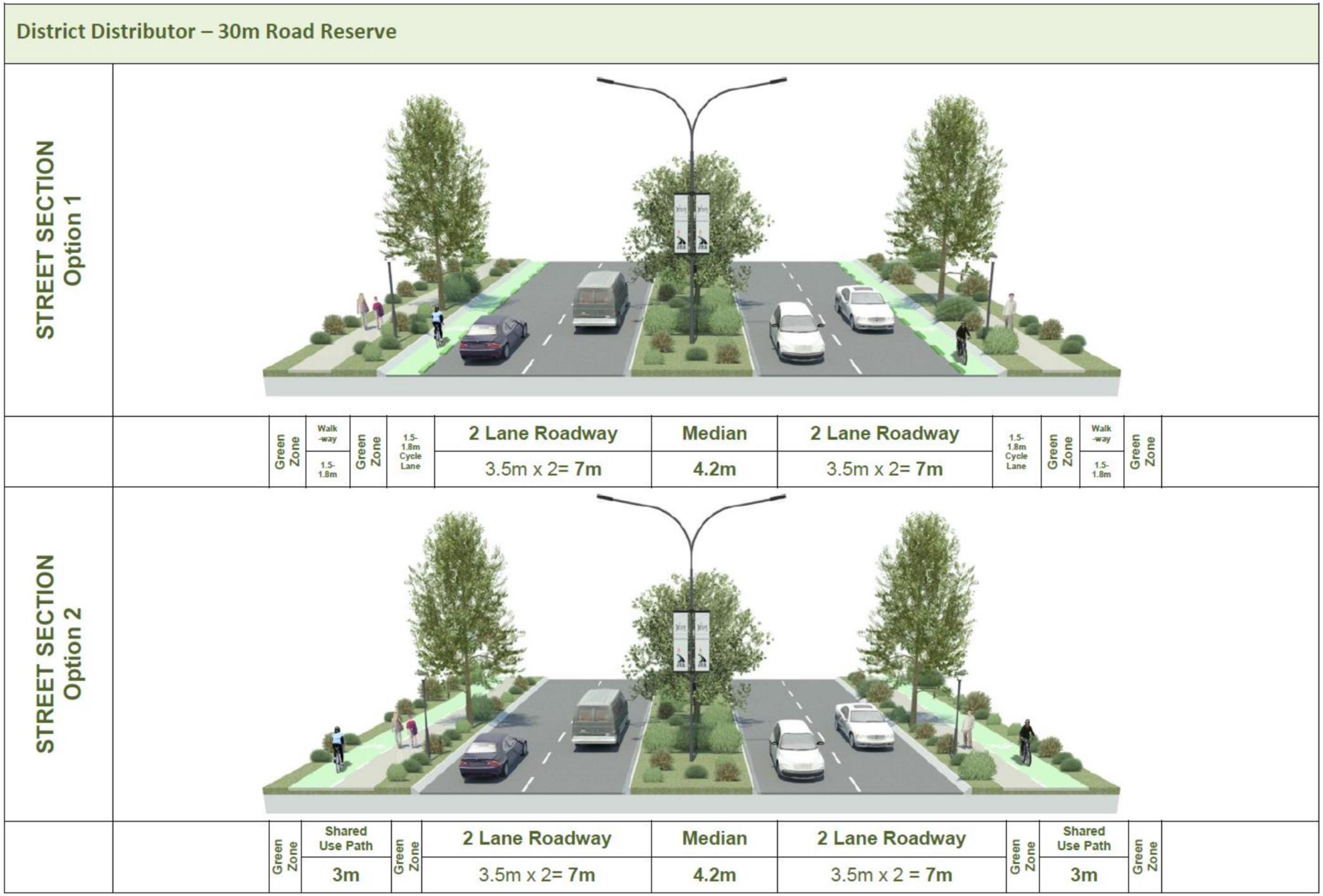


Figure 9.4: Cycleway provision on arterial route as shown in the Cycling Plan (Source: Transport Futures, 2015).

Figure 9.5: Cycleway provision on main collector route in CBD as shown in the Cycling Plan (Source: Transport Futures, 2015).

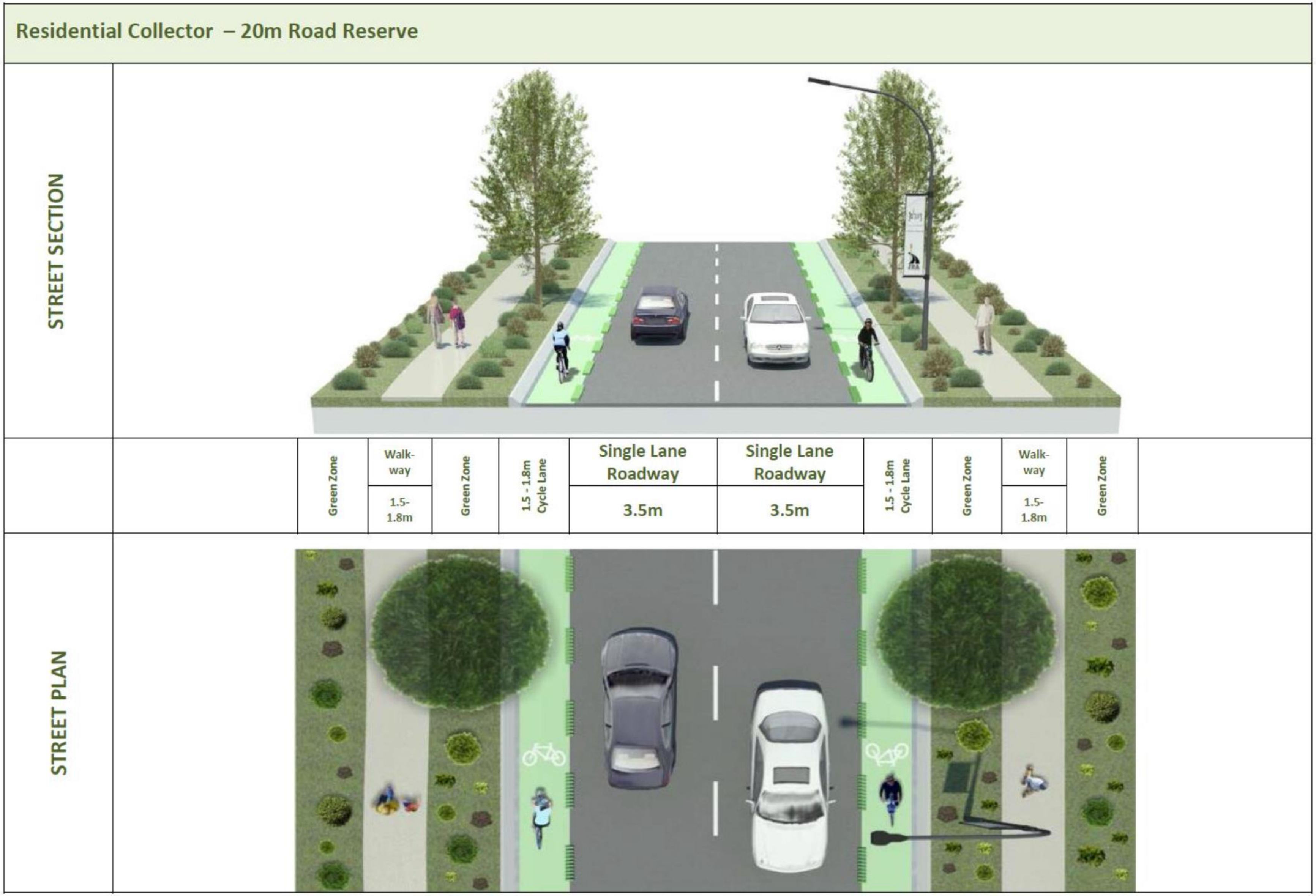


Figure 9.6: Cycleway provision on other collector routes as shown in the Cycling Plan (Source: Transport Futures, 2015).

- Zone S = Stellenbosch central area.

In the network analysis of recommended measures for each key link, a general classification for interventions was worked to as indicated in ***Table 9.3****.*

Table 9.3: Treatment type and code for classification of intervention in the Cycling Plan.

Treatment type	Code
Redevelopment & replan full cross section	Redev
Dedicated cycling provision – class 1	C1
Dedicated cycling provision – class 2	C2
Dedicated cycling provision – class 3	C3
Off road / trail	T1
Widened or improved mix use pathway	NMT
Traffic calming	TC
Cycling in general carriageway	C4

A road section coded as Redev is one which is being proposed for a full cross section replan and is either in process or due to commence. Class 1 to Class 4 cycleway provision has been described in ***Table 9.4****. T1 relates to an off road trail, which is proposed not to be surfaced and is used / proposed as a town based recreational route or a link between surfaced routes. Interventions classified as NMT upgrades cover the following measures:*

- *provision of a shared-use wide pathway for cycling and walking,*
- *widening of an existing pathway to accommodate mixed-use walking and cycling, and*
- *safe crossing points for walking and cycling.*

Traffic Calming (TC) measures include the appropriate treatments to bring down traffic speeds and ensure a safe shared-use situation of the road reserve. This will cover speed humps, street furniture and chokers, signage, speed radars, etc.

Each suggested intervention has been given a priority ranking from 1 to 5. The priority for each intervention is not intended as a final priority ranking. With further detailing, the importance and urgency for interventions on the different links may change. This exercise then should to be considered a first-cut prioritisation and one which begins to inform the scope and required funding of cycle network development. The factors considered in the prioritisation for the network interventions are:

- *network hierarchy, how important the link is in overall network terms;*
- *what the intervention achieves in terms of improving connectivity. For example, does it facilitate linkage where there is currently no effective cycle access, as compared to an upgrading step of a current cycleable link?;* and
- *is the intervention directly aligned to another key municipal programme or commercial investment, thus adding merit?*

The suggested interventions that *cover the priority short-term period* (1 to 3 years) *are largely common to walking and cycling, with 80% of* the *interventions being NMT general. This reflects the overall strategy to place an emphasis on expanding shared use out of roadway facilities to provide basic route connectivity. This pattern changes in the medium term* (4 to 7 years) *towards being a balance between cycle only measures (with many Class 3 and Class 2 roadway treatments) and NMT shared-use link and intersection interventions.*

The paragraphs *above have provided a clear planning reference for cycle network development for all* of *the pathway links. What is equally critical is how we provide for safe and effective cycling movement at roadway intersections.*

Table H.1 *provides a statement of the current issues for each intersection, and some suggested recommendations for improvement to assist cycling and walking conditions are provided.*

Improvements are not specific to cycling, but are important for all NMT modes. ***Figures 9.7*** *and* ***9.8*** *indicate a preferred arrangement for intersections where safe cycling is promoted on the street, either via shared space on calmed roads or via class 2 and class 3 provision. Both diagrams show the position of a safe waiting box for cyclists between the motor-vehicle stop line and the NMT crossing. Where stop lines for intersections are being recessed, provision for a future bike box should be considered.*

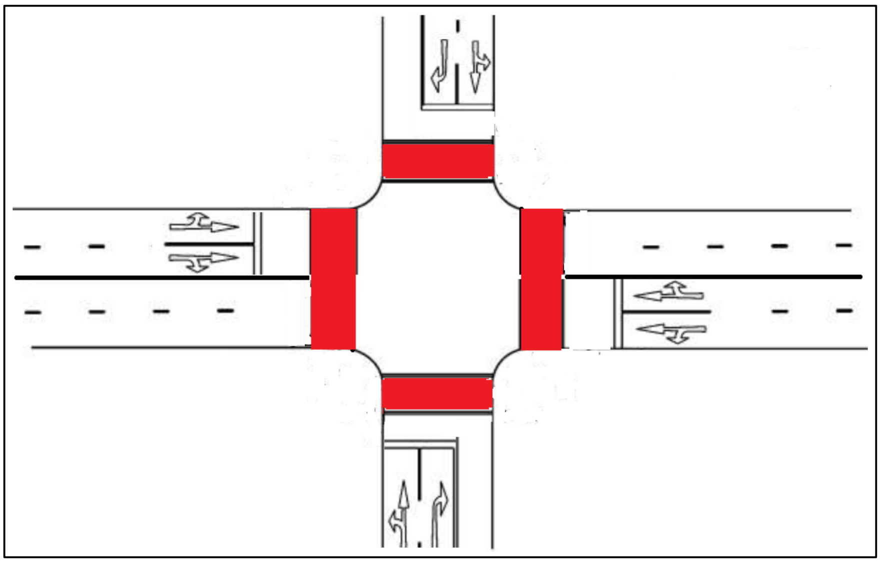


Figure 9.7: Arterial road intersection with advanced stop box for cyclists, as shown in the Cycling Plan (Source: Transport Futures, 2015).

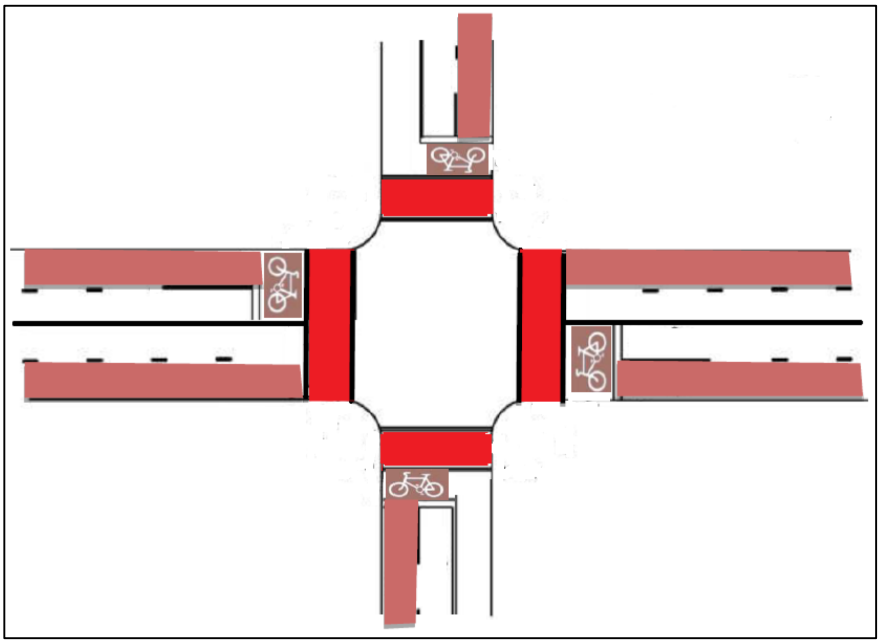


Figure 9.8: Urban distributor road intersection with Class 2 or 3 cycle lane and advanced stop box for cyclists, as shown in the Cycling Plan (Source: Transport Futures, 2015).

The above treatments should suffice to improve walking and cycling provision for the medium term for most of the town's main intersections. However, there are four locations where NMT flows and traffic levels warrant a more detailed investigation into how to achieve an optimum solution, and where grade separation may be a possible viable approach, bringing about significant connectivity and safety benefits. These locations are:

- ***P11, Van Reede Rd and Strand St (R44)**;*
- *P8, Helshoogte / Cluver / Rustenburg;*
- *P6 Bird St and Adam Tas Rd (R44); and*
- *P2 Dorp St and Strand St, (R44).*

R44 / Van Reede Rd *is a very heavily trafficked intersection with high approach speeds especially from the south. The measures required to significantly enhance priority for cycling and walking at grade will reduce some junction capacity at peak times. Van Reede* Rd *dissects Die Boord, which is currently severed from the main school's precinct and town central area due to the busy R44 arterial. The alignment of Van Reede* Rd *also makes a subway link under the R44 a viable possibility, which will be visually much less intrusive compared to a low gradient bridge. This connection will integrate Die Boord with the town with very high resulting benefits.*

9.4.7 NO AMENITIES AT THE DESTINATION

In the future, the *no amenities at the destination* barrier is definitely something that needs to be looked into further, but for the time being, the proposed routes from the Drop-and-Go zone and Park-and-Ride to the schools and campus, respectively, are shorter than 4 km, which should not result in too much perspiration. This is especially true when considering the fact again that most of the cycling will be done in the early mornings and late afternoons of the day.

9.4.8 HELMET LAWS

Reference is made back to ***Section 2.4.1.7.2*** where helmet laws were conversed as a barrier to cycling. Since 2004, it is mandatory for all cyclists in South Africa to wear a helmet. It is recommended though, based on the experience from Australia, that either an amendment to the legislation is to be made so that helmet use becomes a partial law (e.g. only applicable to children), or that the law is repealed completely, because it is in any case not enforced. The protection a helmet provides should be strongly advertised nonetheless, but the choice (as well as the accompanying consequences) of wearing or not wearing a helmet should lie with the cyclists. The advertising can begin at the schools in the form of school education programmes that not only have direct effects in informing children about the benefits of helmet use, but also may additionally confer spill over effects: children take this information home and could serve as role-models for their parents.

For the time being, bicycle helmets form part of the components of the proposed scheme. Helmets with a look unique to each school and the SU are proposed to be both sold and rented to the users.

9.4.9 SOCIAL VARIABLES

The social identity theory and its application to the likely uptake of cycling was introduced in ***Section 2.4.1.7.4***. It was stated that if cycling is seen as an activity exclusive to a small group of interested people, and not as something that can be encompassed into the daily-life routine, this can be a major barrier to the anticipated increase in the bicycle modal share. Motorists need to change their perception of cyclists, but at the same time, it is essential that cyclists behave on the road as they should, and that they stage themselves in the best imaginable light, to not provoke the element of road rage in motorists. Public awareness campaigns, as well as cycling information and training programmes (encompassing training in safe cycling conduct), are proposed to help instigate this win-win state of affairs, which should ultimately lead to a rise in the cycling modal share in Stellenbosch. (See ***Section 9.4.***2, where the required safety education was described in more detail.) It is vital that during each implementation phase, the visual success of the scheme to the remaining motorists is profound, so that the motivations for adoption for the five adopter categories of the Diffusion of Innovation Theory (described in ***Section 1.3.3***) present themselves promptly.

9.5 DESCRIPTION OF THE PROPOSED OPERATION

In this section, the operating procedure for the bicycle-sharing scheme for Stellenbosch is proposed and the required equipment is introduced. The detailed specifications of this equipment and infrastructure are discussed in ***Section 9.6***. From what has been shared about the proposed scheme, the scheme can be recognised as a combination of a community and a residential bicycle-sharing model (refer to ***Section 1.1.1***).

9.5.1 GENERAL OPERATING PROCEDURE

The bicycle-sharing scheme for Stellenbosch is recommended to be an automatic system (see definitions in ***Section 2.4.2.1***). This system allows for a quick and simultaneous check-out of bicycles, which is seen to be a necessity, especially since all users are assumed to check out bicycles at relatively the same time. A manual system would cause queues at the docking terminals that are typically unpopular and may limit the success of the scheme.

The operating procedure begins with registration. A soon-to-be user is to sign up on the website of the system, after which a personal user account is created and the user is requested to purchase a membership in addition to downloading the free mobile application onto his / her smartphone – the access key to the system and a requirement for its use. During the registration procedure, users are also to be asked to which of the in-town destinations they will cycle on a daily basis.

Once a user is registered, he / she may go to any station, and unlock a bicycle for use. A parking lot is to be provided at the Drop-and-Go and Park-and-Ride where the school learners are to be dropped and the SU students and SU staff are to park their cars for the day, respectively. The bicycles are to be docked to a bicycle stand via an electronic lock. Each bicycle and each lock is to have a Quick Response (QR) code and number. A user who is logged into the application (for his / her identity) is to scan the QR code of the electronic lock with his / her smartphone. The system will know which bicycle is docked by which lock from the return of the bicycle by the previous user (explanation follows shortly). After the scan of the QR code, the system is to verify the identity of the user and assign the bicycle number to this user. The system will thus know which user is currently using which bicycle, i.e. if bicycles are not returned, the operator knows who to fine. The user is then free to cycle to school or to the SU campus. Once the user has arrived at his / her destination, he / she is to find an unoccupied lock, scan the QR code of the bicycle (whilst logged into the application) and then scan the QR code of the lock to secure it (a 'beep' sound is to be heard when the lock is secure). The system is to be designed so that the electronic lock can only be secured once the QR code of the bicycle has been read into the application. This is how the system will know which bicycle is docked by which lock. Once the lock has been secured, the system will see the trip as complete and know that the bicycle has been returned. At the end of the school or work day, when the cycle trip is made back to the Drop-and-Go and Park-and-Ride, the system works in reverse. The procedure can be summarised to comprise the following six stages:

1. Register,
2. Rent,
3. Commute,
4. Return,
5. Learn / Work, and
6. Repeat (stage 2 to 4 in the afternoon and stages 2 to 5 the next day).

This procedure is the one that is to apply to the commuters – the users for whom the scheme is to be implemented, and is exactly the same for the check-out of a trailer. It has been mentioned that casual riders and tourists are also to be users of the scheme, however. The operating procedure that applies to these users will be explained in the next paragraphs.

The school learners will spend at least 6 hours at school, and if it is assumed that the SU students and staff will spend the day on campus, the bicycles will be unused for the hours between the AM and PM commute. This is where the tourists and casual riders come into play. Between these hours of the day, the school bicycle fleet is to be used by the tourists and the SU fleet by the casual riders.

To begin with the tourists, it is suggested that guided bicycle tours of Stellenbosch are offered. These tours will begin at the schools, which are located not far from the centre of town. The tourists are not to register with the system, as they are to pay the guide directly who checks out the bicycles under his username. With the bicycle-distribution truck the system is to own, it will even be possible to transport the bicycles to another starting point, e.g. the Jonkershoek valley, and offer a tour from there. It must be noted, though, that the bicycles will be designed for paved roads only and not off-road trails. Mountain-bike tours can, therefore, not be offered with the fleet. Tours are also confined to the morning when the school learners are at school. The proposed reservation system will give a good idea of when the return trip to the Drop-and-Go will be made. If it is found that most learners cycle back straight after school, bicycles could even be rented out from the Drop-and-Go. If return trips are made mainly later in the afternoon, not all bicycles will need to be returned by 14:00. It may even be found that some learners only make the one-way trip in the morning and that they are picked up by their parents from school in the afternoon. Although this is not encouraged, it may allow some guided tours to be offered at any time of the day. These tours are not be seen as a competition to companies that already offer these services. Instead a partnership is to be looked into, which provides a win-win situation for both parties (affordable fleet for the tour operators, and use of the fleet for the operator of the bicycle-sharing scheme). No additional docking stations are to be built for the tourists.

Now to the casual riders: they are to use the fleet docked at the stations on campus. These users are also to register with the scheme, but they have the option of purchasing a membership more suited to their needs, namely a membership that charges per trip. (See ***Section 9.7.1*** for the proposed fare structure.) The casual users are to load money, to be referred to as cycle quota, into their user account, almost like airtime, which gets used up as trips are made. These memberships are not limited to SU students; anyone can be a casual rider. It is assumed, though, that until phase 3 is implemented and in-town stations are all located on campus, mostly SU students will make use of this service. The additional in-town docking station to be located at the Eikestad Mall, and how it is intended to make the scheme more attractive to casual riders, was expressed in ***Section 9.3.3.2***. As is the case for the school fleet, the bicycle-sharing service is only to be available to the casual riders between the AM and PM peak hours, since the fleet will be required for the return trip of the commuters. As their cars are parked at the Park-and-Ride, it can be expected that no one-way trips will be made by the SU-student and SU-staff bicycle-share users. Casual riders are to eventually return their bicycle to the station at which they checked it out; fines are to+ be charged when this is not done, or when bicycles are not returned before the beginning of the PM peak.

The mobile application is to provide additional services to the user, such as keep track on a user profile of the number of trips made, the distance cycled and the number of calories burnt. The application is also to allow the users to reserve bicycles (and bicycle trailers) at specific docking stations for specific times of the day to be guaranteed a bicycle for the desired trip. This is in, fact, strongly advised to be done by the commuters, because of the fleet being used by tourists and casual riders as well. It is to be made possible that reservations can be made on a weekly instead of a daily basis, but it is advised that a fining system is implemented in combination with the reservation system that fines users who do not check out the bicycle they reserved. The application is, moreover, to show real-time updates of dock and bicycle availability, and allow for the upload as well as balance-view of cycle quota. Users are also to be able to report any malfunctions of the system to the back office via the mobile application. The website is to have the same user interface as the application (i.e. users are to be able to log into their personal accounts via the website) but it will not be able to scan QR codes or act as the tool to record trip data; it will keep record of all of the trip data nevertheless, allow for reporting of malfunctions, and provide all the other services: reservation tool, real-time information as well as the option to upload cycle quota and view the quota balance.

The additional services of the mobile application, mentioned in the previous paragraph, are all to be realised by the users of the system. The application is, however, also to act as a data-collection tool for the operator. It was explained how the system will know which bicycle is rented and returned by which user. Along with a GPS-tracking function that is to be developed as part of the application, the users' origins, destinations and travel routes can be logged. Especially in the case of the casual riders, this retrieved data on travel patterns and population movements, will turn out to not only be valuable for the task of bicycle redistribution, but will also aid in determining actual demand (required for future growth), and even aid the authorities in setting priorities for the improvement of NMT facilities.

9.5.2 WHY THIS OPERATING PROCEDURE?

With the increased popularity of bicycle-sharing all over the world, many distinct system designs have been implemented, and various solutions have even been patented. The purpose of this subsection is not to compare the operating procedure discussed above to all of these system solutions and argue why it is the best; this section merely intends to briefly explain why certain alternatives were rejected as part of the general design.

The focus lay on cost-effectiveness, but also quality. Not implementing the typical service terminals at any of the docking stations (refer to ***Section 2.4.2.2***), was seen as a saving in capital investment when in this day and age, most things can easily be done online; all money transfers are to be done online and in advance of the every-day commutes. As stated in the previous subsection, tourists are not required to register online though; their money matters are dealt with directly by the tour guide.

The idea, at first, was to extend the use of the SU student cards to the scheme, but the author was advised by a professional in the field (whose name will not be mentioned) that the cards use 20-year-old magnetic stripe technology that has non-existent security – a cue for a much-needed upgrade of the SU access control system. Besides this though, even if the cards were upgraded to include Radio Frequency Identification (RFID) technology, installing hundreds of card readers, i.e. one for every bicycle dock, was seen as an unnecessary expense. This is why the system was proposed to be switched around: the user is to own the expensive reader / scanner (which he / she is assumed to already have) and the system is to hold that which is to be scanned, namely the free QR codes. Barcodes were initially considered, but it was then realised that these can easily jeopardise the system; a single act of vandalism to the code, e.g. an additional line drawn on the code, will put that specific bicycle or dock out of order. QR codes, on the other hand, have an error margin of approximately 7% to 30%, and in addition can carry up to one hundred times the amount of information as a conventional barcode with a lot less printing space required (Mobile-qr-codes.org). The mobile application is to be designed by a student or group of students who are specialising in Informatics or Computer Science (perhaps as part of a research project) to further save costs; with the correct supervision, the outcome is believed to be the same as that if the job is to be given to a mobile application development company.

9.5.3 BICYCLE MAINTENANCE

For the implementation of phase 1 and 2, warehouse facilities and a workshop, as listed in ***Section 2.4.2.5***, are not yet to be invested in. Multi-skilled staff are to be employed that can perform minor repairs on site, and all major repairs are to be outsourced to a local bicycle shop at least until phase 3 is carried out. A number of these bicycle shops that do bicycle servicing are based in Stellenbosch. These are:

- Flandria Cycles (in Pick-n-Pay Centre off Bird St)
- Mason's bike inn (in the Beyers St pedestrian zone at the Eikestad Mall)
- BMT Cycle Shop (in Dorp St)
- Dirtopia Trail Centre (in Welgevonden)

An employee of Flandria Cycles recommended a bicycle service about every 3 to 4 months, but said that this number is very dependent on the use (or abuse) of the bicycles and the extent of the previous service that was done.

9.5.4 BICYCLE REDISTRIBUTION

In most of the mega cities that have implemented bicycle-sharing, but even in many of the towns, bicycle redistribution, i.e. the balancing of the fleet between all of the docking stations in the system, has become a serious scientific endeavour, and many researchers have tried to come up with mathematical models that were to bring some structure into the operation. Bicycle redistribution was explained in ***Section 2.4.1.14*** along with the dilemma that arises when no redistribution is done.

For the scheme proposed in this research project, the required bicycle redistribution is expected to be manageable, because the trips are a lot less random than in a typical bicycle-sharing scheme. It is, in fact, only the casual riders who could potentially cause a serious imbalance of the fleet, and one-way trips will require the transport of bicycles back to the Drop-and-Go and Park-and-Ride for the following day. It is suggested that only a certain number of one-way trips are to be permitted per user per year; breaching this limit is to result in a fine per one-way trip. Or, a more expensive membership option (that does not fine for one-way trips) is to be sold to the commuters who know from the beginning that many of these trips will be made in the year.

One redistribution truck is to form part of the system that transports bicycles between the stations, especially back to the Drop-and-Go and Park-and-Ride at the end of a day. This truck can also be used for the transport of the fleet for the tourists, and to take bicycles in for servicing. When necessary, ground staff are to cycle between the in-town stations (with redistribution trailers that can transport up to 10 bicycles) and, using real-time information communicated form the back office, ensure the balance of fleet between the stations and that bicycles are present at those stations for which bicycle reservations have been made. These trailers will also have enough room for the staff to carry a toolbox equipped with the tools that are needed for simple bicycle repairs.

9.5.5 RESPONSIBILITIES OF THE STAFF

As described in ***Section 9.5.1***, the system is to 'sort itself out', i.e. it is for the most part to be totally functional without the need for staff. Although one cannot do away with staff completely, staffing (and hence the operating cost) is to be kept to a minimum (especially until the implementation of phase 3), without the user experiencing any form of poor service. The responsibilities of the ground and back-office staff that are to be employed are explained in the following subsections. In the bigger picture, these staff are to be shared with those required for the operation of various other future projects that all strive towards a smarter city, and more specifically smarter mobility. All operations could perhaps be coordinated from a local mini Traffic Management Centre (TMC).

The staff structure that is proposed differs for the various scenarios. The general responsibilities are described here and more details follow in ***Sections 9.6.5 and 12.3***.

9.5.5.1 GROUND STAFF - MAINTENANCE AND REDISTRIBUTION

The ground staff are to be responsible for regular quality-control checks and minor repairs of the bicycles, as well as bicycle redistribution. Since the casual riders are expected to eventually return the rented bicycle to the station they checked them out from, and the school fleet will be watched over by the tour guides, very little (if any) redistribution will be required during the day before the PM commute. Ground staff are thus only to be employed for a few hours towards the end of the day. Their duties are to begin with the quality-control checks of the bicycles and docking-station equipment, as well as the performance of small repairs where necessary. The reports of malfunction received from the users are also to be followed up. This is to be done on a bicycle with a redistribution trailer, and a toolbox on board. Any faults are to be reported to the back office. In the rare case where one or more bicycles are in a state that does not allow for a safe PM commute, these are to be replaced immediately with bicycles from the storage container (see ***Section 9.6.1***).The numbers of all the bicycles (and other equipment) in need of major maintenance are to be recorded. These bicycles are then to be taken to the bicycle shop at the beginning of another working day. The responsibilities of the ground staff, furthermore, include redistribution. Some redistribution may be required before the PM commute (explained in the subsequent subsection), but it will mainly entail taking all unreserved bicycles in town back to the Drop-and-Go and Park-and-Ride in the evening.

9.5.5.2 BACK-OFFICE STAFF

The responsibilities of the back-office staff are to relate mainly to subscription management, customer assistance and CCTV surveillance. Since none of the docking stations are to be manned, users will contact the back office should they experience any problems or require assistance. The system manager is also to sit in the back office; all staff are to report any incidents, e.g. malfunction, to him / her, who will order / take the necessary actions. The bicycle redistribution is to run via him / her too, and he / she is to lock reserved bicycles to other users via the computer system from his /her workstation. It is, moreover, to be the responsibility of the system manager to nurture the relationship with the partners of the system, e.g. the tour guides, as well as the service providers, and is to act as the contact person to these partners and service providers, e.g. the system manager is to coordinate the repair work that is to be outsourced. The back-office staff are also responsible for communicating any malfunction reports to the ground staff who are to look into this further.

For the modifications that include bicycle-sharing for SU students and / or staff, a back-office staff member is to assist the ground staff with the redistribution of bicycles in the evenings.

9.6 SPECIFICATIONS OF EQUIPMENT AND INFRASTRUCTURE

9.6.1 STATIONS

The docking mechanism at all of the stations is to be fixed-permanent (see ***Section 2.4.2.2***), but only to a certain extent, as will be explained in the next paragraphs.

The stations are to comprise bicycle stands, such as those depicted in ***Figure 9.9*** (with two docks per stand), but just smaller in size to accommodate the smaller design of the bicycle (see ***Section 9.6.2***). The stands are also to be positioned much closer together (access only provided from the back and front, not side), and fixed to a module each holding 10 bicycles. Only the modules are to be anchored into the ground, which makes the installation a lot less laborious and also allows for easier repositioning at a later stage. In addition, the fact that there are not to be any fixed service terminals at any of the stations, makes at least the in-town-station docking mechanisms less permanent than is the case for the typical fixed-permanent docking mechanism.

An electronic frame lock, resistant to all forms of cutting (i.e. theft), is to be fixed on either side of the horizontal crossbar of the stand. The lock is to look something like the one shown in ***Figure 9.10*** (without the key of course), which is to clamp around the frame of the bicycle and the latch of the trailer. The locks are to be wired back to a station server via a Local Area Network (LAN) cable. These servers are to communicate with the back office via a wireless Wide Area Network (WAN). This is how the locking and unlocking requests will be verified, and the locks eventually locked or unlocked. As mentioned in ***Section 9.5.1***, a 'beep' sound is to be made when a lock is secured. A double beep sound is to be made for reserved bicycles that users try to check out. In addition to the network server and wireless communication, a network switch and network router will be required for the communication to work. All this equipment is to be housed in an equipment cabinet, and the same configuration is to be installed at all of the stations, even the smaller ones, because it will maintenance easier and also allow for growth.

Figure 9.9: A photograph of an existing bicycle-stand that is to be replicated (with adjustments) for the bicycle-sharing scheme proposed for Stellenbosch.

Figure 9.10: A picture of an existing lock from AXA that shows the recommended design of the electronic locks proposed for the bicycle-sharing scheme for Stellenbosch.

The system is to have internet breakout from the back office to all of the stations via the wireless WAN, so that the users do not require any of their own data to run the mobile application.

Both electricity and solar power were considered for the bicycle-sharing scheme for Stellenbosch as potential power supplies, and unit costs were collected for each. Although no recommendation as to which one should be used is made here, an electrical power supply was included in the cost analysis with an Uninterruptible Power Supply (UPS) as backup, i.e. a power supply that includes a battery to maintain power in the event of a power outage. It should be noted that cabling is still required when solar panels are installed, to carry the generated power to the equipment.

A fence is recommended to be built around only the docking station at the Drop-and-Go for the school learners, but around the entire Park-and-Ride for the SU students and staff (more likely that motor vehicles are parked overnight). Fencing for equipment security at night is believed not to be required at the in-town stations, because the bicycles will either be cycled back to the Drop-and-Go or Park-and-Ride, or redistributed to these locations in the afternoons / evenings. The three schools also have their own security systems in place already. Closed Circuit Television (CCTV) cameras are, furthermore, recommended to be installed at all the stations, excluding those at the schools, as well as infrared perimeter protection beams. Fencing and CCTV are costly investments, however, and for this reason scenarios with and without this type of security were tested (see modifications in ***Section 9.6.6***). Within the boundaries of the fence, the bicycles (to be corrosion-resistant) are to stand in the open. One storage container is to be sited at the Park-and-Ride, though, to house bicycles in need of major repairs, spare parts, as well as the redistribution trailers and toolboxes of the ground staff overnight. Bicycle storage overnight, over weekends, and during the school and SU holidays (a protection measure against adverse weather conditions and theft), may be looked into, but was not accounted for in the cost analysis of this research project.

In Tokyo, the unbelievably high real estate prices led Japanese engineers to take bicycle parking or storage to a whole other level, literally. They developed a robotic storage system that stows bicycles up to 12 m below ground level (Gizmodo, 2013). This innovative idea, depicted in ***Figure 9.11***, is based on the concept of "culture above ground, function underground" (Millennium Hollywood, 2013). Although this station type is by no means proposed for Stellenbosch at this stage, it is mentioned, because it is to be evidence for how the bicycle has been 'reinvented' in mega cities and the extreme measures that are turned to, to make it stay.

9.6.2 BICYCLES AND BICYCLE TRAILERS

The design of the public bicycles for Stellenbosch should incorporate as many of the features described in ***Section 2.4.2.3*** and listed in ***Figure 2.8*** as is realistically feasible. These features include:

- unisex,
- distinctive appearance (lime green in colour as expressed in ***Section 9.4.2***),
- easy riding with everyday clothing,
- adjustable cushioned saddle,
- upright geometry / riding position (improves ability to see traffic),
- step-through frame (provides easy use for novice cyclists),
- robust and vandal-proof,
- corrosion-resistant
- puncture-proof tyres,

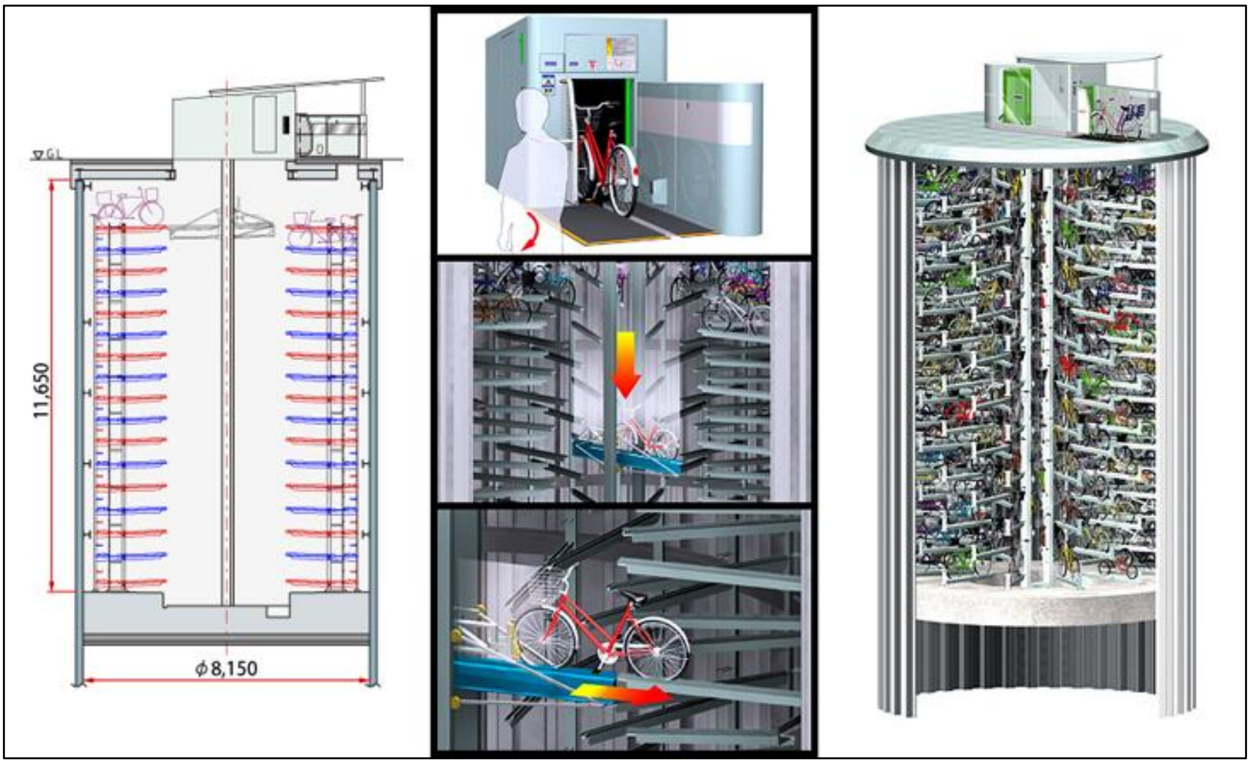


Figure 9.11: The Japanese Eco-Cycle bicycle parking system (Source: Gizmodo, 2013).

- uncommon dimensions,
- require special tools for disassembly,
- non-slip handlebars,
- self-generating front and rear lights,
- reflective strips on wheel and pedals (especially for driving in the dark),
- front and rear brakes, pedal brakes,
- enclosed, stainless steel all-weather chain,
- finger touch bell,
- kick stand,
- front and rear mud guards, and
- low centre of gravity.

South Africa does not manufacture bicycles in any large quantities; bicycle parts are imported from bicycle-producer countries such as Taiwan, and then assembled locally. This is a stumbling block to a custom-designed bicycle for Stellenbosch. This is not to say that a custom design is unmanageable to put into operation though. It is believed that finding a solution to this hurdle is essential in ensuring the success of the scheme.

Whilst the intention of this chapter was not to propose the ultimate design of the bicycle, several off-the-shelf options were looked into, so that a cost could be assigned to the bicycles.

Figure 9.12 shows the bicycle of the *Divvy* bicycle-share programme in Chicago – an example of what the bicycle for Stellenbosch could look like. It is a step-through frame as shown in the figure that was sought after. An example of a similar off-the-shelf bicycle is the Silverback Senza 26 shown in ***Figure 9.13***, quoted at ZAR 3,690 on *Bicyling.co.za*. To take into account the barrier of *too much and / or heavy baggage*, cargo bicycles were also considered. According to Camissa Bicycles, the Danish *Bullitt* cargo

Figure 9.12: The Divvy (bicycle-sharing scheme of Chicago) bicycle.

Figure 9.13: Off-the-shelf Silverback Senza 26.

is regarded the best cargo bicycle in the world (see ***Figure 9.14***). Camissa Bicycles first distributed these bicycles in South Africa in 2013, but due to a high exchange rate and thus a lack of interest, the distribution has been paused. The bicycles were quoted at approximately ZAR 50,000 – a price that is not financially feasible for a bicycle-sharing scheme that is intended to be affordable to its users and that has the potential to have a fleet size of a few hundred bicycles. Furthermore, the option of foldable bicycles was explored – bicycles that have become very popular overseas, because of the easy-storage solution they provide and the fact that they can be carried onto buses and trains effortlessly. ***Figure 9.15*** is an illustration of such a bicycle. The bicycle fleet of Singapore's bicycle-sharing scheme *Isuda*, for example, comprises foldable bicycles. *Dahon* is a well-renowned and top-selling brand of folding

Figure 9.14: Danish Bullitt cargo bicycle.

Figure 9.15: Example of an off-the-shelf foldable bicycle from Dahon.

bicycles that also has distributors in South Africa. On *Futurama*, folding bicycles are advertised from ZAR 3,995. Another big boom in Europe is that of the electric bicycle, e-bike for short. These bicycles have an electric motor that kicks in as soon as the cyclist wishes it to do so. *Gocycle* is an electric, two-wheel drive bicycle designed in London. It is shown in ***Figure 9.16***. These e-bikes are also for sale in South Africa at Cycle Lab in Sandton, for example, for ZAR 59,999. Although e-bikes may be the future of bicycle-sharing, since they can increase the maximum acceptable cycling distance without an increase in physical exertion, they do not seem feasible for the start-up scheme proposed for Stellenbosch.

In summary, the foldable bicycle has a look that is currently not often seen in South Africa, which makes the parts uncommon in dimension and less attractive for theft. In addition, these bicycles are not inferior to the regular bicycle in terms of durability and performance, and their lightweight feature makes redistribution less of a strenuous job. The bicycles also require a lot less storage space. As a result, folding bicycles are proposed as the bicycle for the Stellenbosch bicycle-sharing scheme with

Figure 9.16: Gocycle foldable e-bike.

the add-ons listed earlier. Should it, however, be agreed that the bicycles are to stand outside all year round (hence no bicycle storage over weekends and during holidays), it may be an option to go for the general design of the folding bicycle, i.e. smaller wheels, without it actually being able to fold. This means that there will be less parts that can break, and thus less maintenance as a result.

Front carriers and bicycle trailers have been briefly mentioned in ***Section 9.4.5***. They are the proposed alternative to the cargo bicycle in terms of providing storage space for any baggage the bicycle-share user may have. The front cargo basket *Dahon* offers as an accessory to the bicycle is shown in ***Figure 9.17***. For the case where more storage space is required, bicycle trailers are to be made available to the users for rent at all of the stations (except at the schools, which excludes the Drop-and-Go zone). *Community Bikes SA* and *Zambikes* in Zambia initiated community projects that have given unemployed welders the opportunity to manufacture bicycle trailers. These trailers can be easily to be

Figure 9.17: Dahon front cargo basket.

photo of each of the trailers. A similar project (manufacture of custom-designed trailers) is proposed introduced in Stellenbosch. In addition to being used for books, personal computers and sports gear, hitched or unhitched to a bicycle, i.e. they can be used on an as-needed basis. ***Figure 9.18*** portrays a for example, the trailers may also prove to be attractive for shopping to the casual riders residing on campus.

Figure 9.18: Bicycle trailers from Community Bikes SA (left) and Zambikes (right).

In addition, as referred to in ***Section 9.5.1***, each of the bicycles is to be equipped with a QR code and a GPS tracking device (e.g. from *Spybike*), as well as branding and advertising space. Although the design is not that of a foldable bicycle, ***Figure 9.19*** illustrates the potential branding and advertising space on a bicycle.

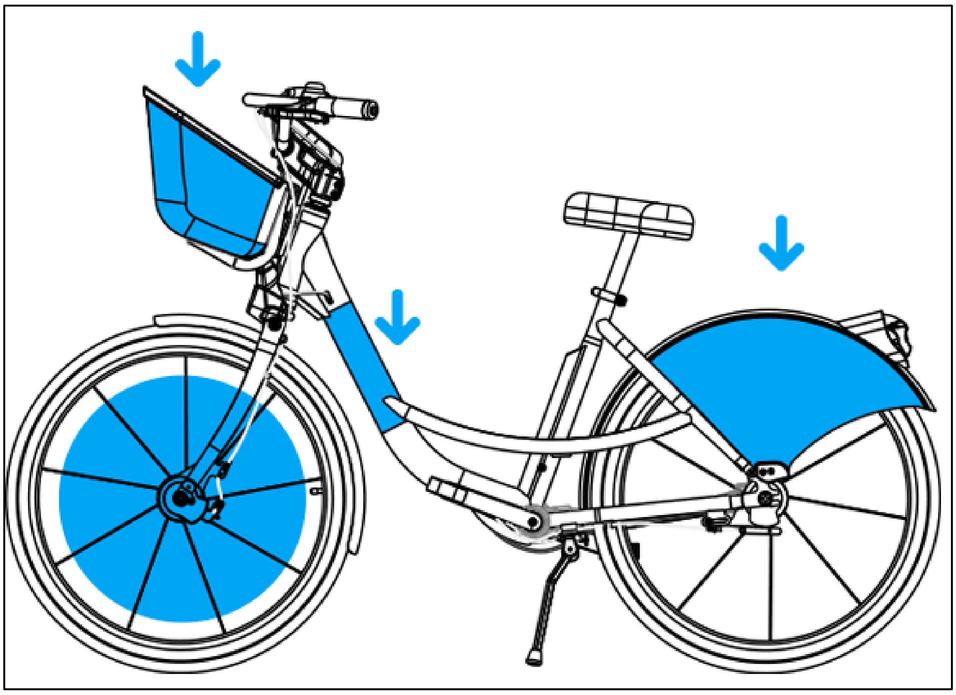


Figure 9.19: Potential branding and advertising space on a bicycle (Source: Smoove, 2015).

9.6.3 BICYCLE FACILITIES

Refer to ***Section 9.4.6***.

9.6.4 BACK OFFICE

For efficient operation at the back office, a workstation (including a telephone) is to be set up for every member of staff (on shift), and one laser printer is to be installed for all to share. Other hardware that is to be installed is a network server, a network router, a network switch, as well as a system manager and network storage manager for CCTV surveillance. In terms of software, a core module, an operating system (i.e. Microsoft Windows), an office system (i.e. Microsoft Office), antivirus protection, a licence for the CCTV surveillance system and bank transaction reconciliation are to be installed.

9.6.5 GENERAL

In principle, the system is to be open for use 24/7 for the five weekdays of the week. The back-office staff are, however, only to work in shifts from 7AM to 7PM, and only reserved bicycles in town are not to be redistributed to the Drop-and-Go and Park-and-Ride at the end of the day. The 24/7 rule thus actually only applies to the commuters and the check-in time of the bicycles to the Drop-and-Go and Park-and-Ride; offering evening and weekend tours to tourists can, however, be considered.

It would be ideal, if a sponsor could be found for helmets, but in the case where not, helmets are to be available for sale to the users online. It is then to be the reasonability of the user to carry this helmet around with them.

In terms of security at night, the system is to partner with a local tactical response unit that is to take action when the infrared perimeter protection beams send off an alarm. The gate at the Drop-and-Go and Park-and-Ride is also to be locked at night, which only users logged into the application are to be able to unlock with their smartphone.

Indemnity or agreement-to-the-conditions forms are to be signed by all the bicycle-share users, or the parents in the case of the school learners. These agreements are to state the duties of the system operator regarding the maintenance and well-keeping of the bicycles, and also the duties of the users regarding safe use of the bicycles. All the bicycles are to have a sticker on them clearly reading "Ride at your own risk. All bicycle laws apply".

In addition, it should be considered to get insurance cover for the damage to, and the vandalism or theft of, the bicycles and other service equipment. Insurance is not further discussed in this research project and was not included in the evaluation of the costs of the theoretical bicycle-scheme.

9.6.6 MODIFICATIONS TO THE OPERATIONAL MODEL

In ***Section 4.5.2.2***, the modifications to the operational model were described as:

1. "all components included" (base case B9), and
2. "excluding luxuries" (modification M15).

The following components of the scheme were included in the list of 'luxury' items:

- bicycle tracking against theft,

- bicycle trailers (since the front basket of the bicycle still provides a storage option)
- CCTV surveillance,
- fencing around the entire Park-and-Ride instead of just the docking station, and
- bicycle redistribution trailers and toolboxes for ground staff

Although the redistribution truck is an expensive capital cost, the system cannot operate without this truck, and it was thus not considered a 'luxury' item. To remove fencing completely did also not seem sensible, as this is seen to lead to a security issue, especially because the stations are to be unmanned.

The detailed cost calculations of the two modifications per scenario are given in ***Section 12.3***.

9.7 MEMBERSHIP AND USAGE FEES

As stated in ***Section 4.8***, the proposed annual membership and usage fees were calculated from the present travelling expenses of the potential users, and the Matie Bike subscription fee.

Although monthly memberships are also to be made available to the users, along with other options that differ for the three road-user groups, for the economic evaluation of this research project, only a fixed annual membership was considered for the commuters. A single, per-trip rate was applied for the casual riders and the rental of bicycles to the tourists.

Assuming an average system mean speed of 20 km/h for the scholars (to and from school), and an average of 35 km/h for the SU students and staff, the total VOC calculated for these user groups for 200 days in the year were ZAR 5,143 and ZAR 6,738 per user per year, respectively (using the equation given in ***Section 4.7.3.1***). An average cycling distance of 2.0 km was used for the school learners and 3.3 km for the SU students and staff. As was made known in ***Section 4.7.4***, the vehicle registration fee for the SU students was ZAR 288 in 2015. The fee of the school bus from Somerset West was ZAR 9,000 for the year if the fee was paid in one instalment (otherwise slightly more). The total cost for renting a Matie Bike in 2015 was ZAR 1,300 for the year or part thereof.

An annual membership of ZAR 3,000 was decided on and applied in the cost analysis for the commuters for all 15 years, and ZAR 7 was used for the casual riders per trip (assuming all trips are shorter than 30 min). ZAR 75 was worked with for the rental of bicycles to tourists, assuming that the guided tours are outsourced to an existing bicycle rental company / tour operator. These rates are all 2015 Rand values.

9.8 EQUITY CONSIDERATIONS

Since the potential users of the bicycle-sharing scheme belong either to the medium- or high-income group, there are not many considerations for equity that are to be made.

It is to be made possible that memberships can be purchased online with both a credit card and a debit. Whilst it is assumed that not all of the SU-student potential users will have credit cards, it is assumed that they are in the possession of a debit card.

It is also assumed that in five years' time (when the system is to be launched) all potential users will be the owner of a smartphone. In the case where not, the user is to call the back office, identify him or herself, and read the number of the lock he / she wishes to unlock.

9.9 PROMOTION OF THE SCHEME

Reference is made back to ***Section 2.5***, where travel-behaviour-change theories, as well as marketing strategies and marketing activities related to a specific transportation mode or service, in this case bicycle-sharing, were defined and discussed. To compete with the private-vehicle mode of transport, attract many users and break the resistance to change, various forms of marketing for the bicycle-sharing system are to be performed. Some of these awareness campaigns have been referred to in ***Section 9.4*,** but are proposed again here.

With the knowledge from the travel-behaviour-change theories as to what stimulates consumers to make choices, how these choices are made and when changes in behaviour occur, it is suggested that both undifferentiated (appeals to the public at large) and differentiated (appeals to the different road-user groups individually) marketing is to be undertaken by performing information distribution and advertising (the marketing activities).

Those marketing activities that were named in the literature review and are recommended to be carried out for the promotion of the proposed bicycle-sharing scheme for Stellenbosch, are given in bullet-form here, alongside additional ideas. Some of the awareness campaigns are not to be specific to bicycle-sharing; they are to address the mode of cycling as a whole.

- It is suggested that the launch of the scheme should be accompanied by a professional media campaign that includes the development of a unique and highly recognisable brand, as well as a social identity. The first step in terms of branding has been taken in the form of the design of a logo. ***Figures 9.20*** to ***9.23*** show the alternative logos that were designed.
- The information campaigns on bicycle-sharing are to attempt to improve the image of cycling in the eyes of the public (i.e. that it is a sustainable, healthy and safe mode of transport), and communicate all the benefits (especially the financial savings) the mode is able to afford to its users and society as a whole. The campaigns are, furthermore, to stress the fundamental role that bicycle-sharing plays in moving towards a smarter town.
- It is to be highlighted that cycling, in general, can be encompassed into the daily-life routine as a way of life and that it is not an exclusive mode (even the commuters can become cyclists now).
- Emphasis is to be placed on the fact that bicycles do belong on the roads; they are not invaders of road space.
- The scheme is to be promoted frequently and widely amongst different channels, with public officials and other celebrities partaking in this promotion. These channels, as also identified by the Cycling Plan, could be brochures, newsletters, the internet (websites, social media and online communities), competitions (that create material for communication use), traditional media (local print media and local radio) and stakeholders. The aim is to create dialogues, since the provision of bicycle facilities alone cannot and will not attract as well as retain the number of users it is envisioned to do.

Figure 9.20: Option 1 – logo suggestion for the bicycle-sharing system for Stellenbosch.

Figure 9.21: Option 2 – logo suggestion for the bicycle-sharing system for Stellenbosch.

Figure 9.22: Option 3 – logo suggestion for the bicycle-sharing system for Stellenbosch.

Figure 9.23: Option 4 – logo suggestion for the bicycle-sharing system for Stellenbosch.

- The school learners and SU students are to be targeted individually, as they are believed to be the critical mass in the bigger picture.
- There has been a lack of commitment on the part of the schools to adopt a more sustainable transportation policy and encourage greener travel behaviour. Initiatives are to be prompted at the schools that include, for example, the setting of motor-vehicle-use reduction targets (for the school, as well as each grade and class), and the instigating of a reward system for those that cycle, in the form of house points, for instance.
- In addition to general marketing, specific actions for driving membership sales are to be implemented at the beginning. These could include free or discounted trips in the first month/s, pre-sales of discounted long-term memberships before the launch of the scheme, and incentives for members from, for example, franchised businesses and employers.
- Pro-bike events, such as cycling-to-school days or ride-to-work days, are to be hosted regularly to not only strive towards the promotion of cycling, but also towards ensuring that the bicycle is seen as the mode of transport of the "in-group".
- And, as pointed out by the Cycling Plan, the strategic cycling plan is to be a transparent document in which the public is to find a description of the way forward for Stellenbosch, and the valid place and permanence that cycling is to have in the town.

9.10 BUSINESS MODEL

The proposal of the business model for the theoretical bicycle-sharing scheme fell outside of the scope of this research project that was to evaluate the economic viability of such a scheme. It is suggested though, that both a public and a private model should be looked into. The execution of the Cycling Plan – a plan that has yet to finalise its funding sources – is assumed to 'dry out' many of the potential sources; private investments may thus just be the way to go.

9.10.1 OWNERSHIP AND OPERATIONS

Reference is made back to ***Section 2.4.1.4.2***, where an overview of various business models was given. A public-private partnership with an advertising company to the extent described in ***Section 2.4.1.4.1***, does not seem practically feasible for Stellenbosch, since it is assumed that advertising space will be limited to the free spots at the docking stations and on the bicycles (see ***Section 9.6.2***), as well as trailers and helmets.

9.10.2 FUNDING SOURCES

9.10.2.1 SPONSORSHIPS

It is believed that if a green and sustainable project such as bicycle-sharing, that has the potential to improve the liveability of an entire population as part of a broader 'smart-city' vision, is sold correctly, it is a sponsorship opportunity that may be attractive to both local and international companies.

Various sponsorship models should be looked into. The different options include:

1. A single sponsor that donates money in return for full branding of the system infrastructure.

2. Multiple smaller sponsors donate money for sponsorship opportunities (e.g. a sponsor per station, or a sponsor just for the helmets or the trailers).
3. A single large sponsor donates money in return for branding of certain parts of the infrastructure, but still allows smaller station-sponsors.

The Cycling Plan makes mention of Dutch and Danish agencies that are interested in partnering with the municipality to execute the plan, and also of the German Development Bank (GTZ) that is supposedly active in South Africa on sustainable transport initiatives that focus on NMT.

9.10.2.2 REVENUE

The sources of revenue to be available to the operator are dependent on the business model that is agreed on in the end. If private sponsorships are obtained, the advertising revenue is most likely to fall away, and only the membership revenue will remain.

In this research project, it was assumed that free advertising space will be limited to the stations, the bicycles, the helmets, and the trailers. It was, however, only the advertising revenue from the stations and the bicycles that was included in the CBA. In the financial feasibility report prepared for the CoJ (De Beer & Valjarevic 2015) that was mentioned in ***Section 2.4.1.3***, advertising was also considered as a potential source of revenue, and a revenue of ZAR 175 was applied per bicycle. The revenue potential at the sites was said to be dependent on the characteristics of each of the sites. The sites were graded according to:

1. the Living Standards Measures,
2. the traffic (high, medium or low congestion)
3. clutter (presence of other advertising material, sign boards, obstructions, etc.), and
4. the proximity of the sign to passing traffic.

Based on these characteristics, sites were then categorised as:

- premium (the sites rates favourably on all four characteristics – ZAR 7,000 per site per year),
- impact (the site rates favourably on any three characteristics – ZAR 5,000 per site per year), and
- strategic (the site rates favourably on any two characteristics – ZAR 2,100 per site per year).

It was assumed that the Drop-and-Go and the Park-and-Ride are impact sites, and that the in-town stations (excl. the stations at the schools) are strategic sites.

The proposed membership fees have been discussed in ***Section 9.7***. How these revenues were included in the cost analysis is shown in ***Section 10***. For the M13 and M14 modification a 10% decrease and a 10% increase, respectively, on the total calculated potential revenue was applied.

10 BICYCLE-SHARING COST ANALYSIS

10.1 SYSTEM UNIT COSTS

In this chapter, the various unit costs per system component (most of which were identified in ***Section 9***) are given. The results of the cost analysis are presented per scenario in ***Section 10.3***. As described in ***Section 4.6.1***, the project costs were divided into three categories, namely:

1. capital costs (construction costs and equipment costs),
2. launch and implementation costs, and
3. running costs (operating and maintenance costs).

It was also stated, that the cost estimates are the results of requested and received quotations, but also information collected via e-mail correspondence and during personal interviews. For the cases where official quotations were received, these are included on the attached CD, and reference is made to these in the text.

All costs exclude Value Added Tax.

10.1.1 CAPITAL UNIT COSTS

The capital costs are the expenditures relating to the construction of the system facilities as well as the procurement of the equipment, and include planning and administration costs. These expenditures are viewed as once-off costs that have both a physical and an economic life of multiple years.

The capital costs of this research project were the construction costs of the Drop-and-Go and Park-and-Ride, and the equipment costs of the system. No construction costs were expected for the in-town docking stations; only implementation costs were applied. As also mentioned in ***Section 4.6.1***, right-of-way costs were not included.

10.1.1.1 CONSTRUCTION UNIT COSTS

The layouts of the Drop-and-Go and Park-and-Ride have not yet been mentioned; it is a parking lot with a docking station on one of its sides. The parking-lot design that was applied in this research project (to evaluate the construction costs) is shown in ***Figure 10.1***. It by no means to be seen as the final design. This design was made to fit into the area designated for the Drop-and-Go. It is characterised by its one-way traffic flow and 45° parking bays. The parking lot was designed according to a combination of the South African Parking Standards (DoT, 1985) and the dimensions suggested by Bester and Da Silva (2012) in a paper that recommends an urgent update of the 1985 standards. The areas shaded in light blue represent slightly elevated areas of segmented paving, i.e. walkways, and soft landscaping. The grey area, shown to have a width of 12.2 m, is set aside for the docking station. The remaining area is for the motor vehicles and comprises an asphalt base. As stated in ***Section 4.6.1***, the costs for the parking lots were determined from the existing BoQ of a Stellenbosch parking project, which is confidential, and from which only totals could be extracted. The construction costs are shown in ***Table 10.1***. To acquire the cost of the items listed with an asterisk, the total cost that was specified for that item in the BoQ was multiplied by a ratio of the area of the parking lot of the Drop-and-Go for bicycle-sharing and the SU-project area.

An engineering consultation fee (taken to be 8% of the total parking-lot construction cost) was added

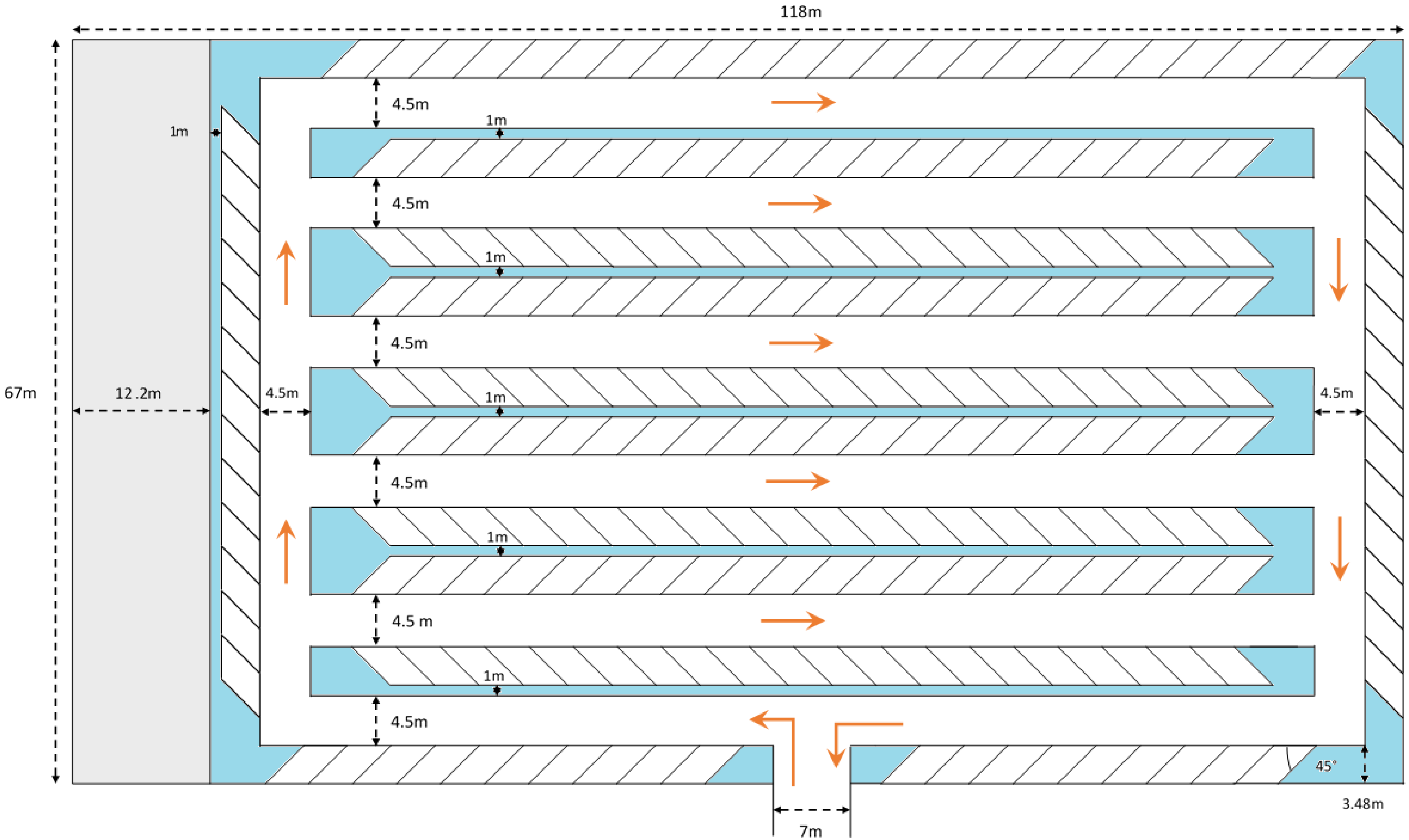


Figure 10.1: Design of the parking lot applied in the cost analysis of this research project.

Table 10.1: A breakdown of the construction costs for Parking Lot 1 at Trumali St.

Cost item	Unit	Quantity	Rate in ZAR	Amount in ZAR
General Items				
Establish facilities on site	SUM			79,000
Soft landscaping	SUM			100,000
Hard Landscaping – fencing and a gate (supply plus installation)	SUM			159,404
Lighting and electrical (supply plus installation)	SUM			100,000
Site Clearance				
Clear, grub and dispose of material at off-site location	ha	0.84	90,000	75,600
Remove topsoil to nominal depth of 150 mm and stockpile	m^3	1260	15	18,900
Earthworks				
Excavation*	SUM			166,196
Pipe trenches*	SUM			26,381
Roads / subgrade*	SUM			31,035
Bedding (Pipes)*	SUM			18,248
Cable Ducts*	SUM			8,797
Stormwater Drainage*	SUM			99,587
Segmented Paving				
"Corobrik" 110 x 220 x 70 mm "De Hoop Brown" Clay Pavers, Headercourse on all edges rest herringbone bond on 20mm bedding sand for sidewalks	m^2	740.94	252.60	187,161
Cutting units to fit edge restraints	m	1072	12	12,864
Kerbing and Channelling*	SUM			67,050
Ancillary Roadworks				
Sign faces with painted backgrounds	no	6	600	3,600
Sign supports	no	6	300	1,800
Excavating and backfilling with 15MPa/38mm concrete for sign supports	no	6	60	360
Non-reflectorised paint applied at nominal rate of 42 l/m^2	SUM			10,354
Setting out and premarking	SUM			1,021
Pavement Material of Gravel Material	SUM			640,000
Prime Coat*	SUM			76,288
Asphalt Base and Surfacing*	SUM			972,240
TOTAL	**2,855,887**			
Engineering Consultation Fees	%	0.08		228,470
CONSTRUCTION CONTINGENCY	142,794			
TOTAL CONSTRUCTION COST	**3,227,152**			

to the calculated construction costs, and furthermore, a construction contingency of 5% on the total estimated cost for the parking lot was included to account for the uncertainty in the approximations derived from multiplying certain costs by the ratio of the areas previously defined, and also to account for inflation. A shadow price factor of 0.89 was moreover applied.

The construction phase of the parking lots was assumed to span over less than a year; no discounting of costs thus had to be dealt with. The cost of the parking lot for the Drop-and-Go shown in ***Figure***

10.1 (with those specific dimensions) was calculated as described above, and the cost of the Park-and-Ride was then determined by multiplying the cost for the Drop-and-Go parking lot by the ratio of the two parking-lot areas. There are two vacant areas of land at the Die-Boord site (identified for the location of the Park-and-Ride) that are separated by Rhodes-Noord Rd. If parking is to be made available to the total number of identified SU-student and SU-staff potential users, a parking lot would have to be built on both these sites with the docking station deployed in the middle. From here on forth, the parking lot at the Drop-and-Go is referred to as Parking Lot (PL) 1, the parking lot at the Park-and-Ride located closer to the R44 as PL 2, and the second parking at the Park-and-Ride as PL 3. In the scenario analysis, the full costs of the parking lots were considered for all the modifications to allow for growth and side-step further phases of construction later on. For the Park-and-Ride, however, the costs of Parking Lot 2 were omitted for the modifications with a small scheme size.

With rounding off, the construction cost of Parking Lot 1 is ZAR 3.23 million. The area of PL 1 is 70 x 120 m = 8,400 m^2 (204 parking bays), whilst the areas of PL 2 and 3 are 75 x 100 m = 7,500 m^2 (204 parking bays) and 165 x 100 m = 16,500 m^2 (448 parking bays), respectively. Before multiplying by the ratio of the areas, an adjustment had to be made to the hard landscaping cost, because the fence at the Park-and-Ride is to be built around the entire area as opposed to only around the docking station as at the Drop-and-Go. The engineering consultation fee was also not added again, and the contingency for Parking Lot 1 had to be subtracted, after which a new contingency was determined on the total calculated for Parking Lot 2 and 3, respectively. The construction costs for Parking Lot 2 and 3 thus came to be ZAR 2.88 million and ZAR 6.26 million, respectively.

10.1.1.2 EQUIPMENT UNIT COSTS

All the equipment that is to form part of the bicycle-sharing system has been identified in ***Sections 9.5*** and ***9.6***. The estimated cost of each item is given in ***Table 10.2***.

As described in ***Chapter 9***, unique helmets are to form part of the system. The estimated unit cost of a helmet is given in ***Table 10.2***, but they were not included in the cost analysis; the sale is to support itself, mainly in the form of sponsorships. The same goes for solar power: the unit cost of a solar panel is listed in ***Table 10.2***, but only an electrical source of power was included in the cost analysis. The bank transaction reconciliation fee was directly subtracted from the potential revenue during the revenue assessment (see ***Chapter 11)***.

Table 10.2: A breakdown of the equipment costs (unit prices) for the bicycle-sharing system.

Cost item	Unit	Rate in ZAR
DOCKING STATIONS		
Bicycles		
Standard bicycle	no.	4,000
QR code_bicycle	no.	free
GPS tracking	no.	2,000
Front carrier	no.	350
Bicycle trailer	no.	800
QR code_bicycle trailer	no.	free
Advertising	no.	paid by company advertising
Helmet	no.	500
Bicycle stands		
Standard docking stand	no.	800

Electronic lock	no.	1,000
QR code_electronic lock	no.	free
Storage container		
Standard 12m container	no.	26,000
Surveillance		
Pan Tilt Zoom (PTZ) CCTV camera	no.	30,000
Mast to mount camera (incl. equipment cabinet)	no.	20,000
Docking Station Hardware (incl. installation)		
Station server	no.	30,000
Station network switch	no.	25,000
Station network router	no.	37,500
Station equipment cabinet	no.	20,000
Station wireless communication	no.	32,500
Station UPS	no.	10,000
Infrared perimeter protection beams - 30m (x4)	no.	700
Infrared perimeter protection beams - 60m (x4)	no.	1,000
Infrared perimeter protection beams - 100m (x4)	no.	1,100
Cabling for power supply	per metre	15
Electrical sundry installation	no.	3,500
Solar panels (as alternative)	no.	3,000
BACK OFFICE		
Back-Office Hardware (incl. installation)		
Back-office workstation	no.	25,000
Laser printer and toner cartridge	no.	6,500
Telephone	no.	500
Back-office server	no.	75,000
Back-office network router	no.	70,000
Back-office network switch	no.	25,000
System Manager for CCTV	no.	90,000
Network Storage Manager for CCTV	no.	250,000
Back Office Software		
Core Module	no.	25,000
Operating system (Microsoft Windows)	no.	incl. in workstation price
Antivirus protection	no.	incl. in workstation price
Office system (Microsoft Office)	no.	incl. in workstation price
Licence fee for CCTV	no.	18,000
Bank transaction reconciliation	%	1% on the value of the reconciled amount
GENERAL		
Maintenance / redistribution		
Maintenance / redistribution truck	no.	260,000
Maintenance / redistribution bicycle trailer	no.	10,000
Bicycle repair toolbox	no.	3,500
Walkie talkie (set of 2)	no.	650
Mobile application	no.	25,000
As-built documentation	no.	12,500

An official quote for a truck that is to transport bicycles in future was received from Hino, and is included as part of the attached CD. Most of the cost estimates, though, especially those for the station and back-office hardware as well as software, were acquired from professionals in the field during personal interviews or the internet.

10.1.2 LAUNCH AND IMPLEMENTATION COSTS

The launch costs, also referred to as start-up costs, along with the implementation costs, are the costs associated with establishing the system. This includes bicycle and station assembly, both station and back-office hardware and software installation / set-up, staff training and pre-launch promotion of the system. Many of the installation costs for this research project were quoted to be encompassed in the cost estimate of the equipment. ***Table 10.3*** lists the launch and implementation costs comprised in the cost analysis.

Table 10.3: A breakdown of the launch and implementation once-off costs for the bicycle-sharing system.

Cost item	Unit	Rate in ZAR
STATIONS		
Installation (incl. labour) - docking stands	included in equipment cost	
Installation (incl. labour) - electric locks onto docking stands	included in equipment cost	
Installation (incl. labour) - QR codes onto bicycles, trailers and electronic locks	no	10
Installation (incl. labour) - docking station hardware	included in equipment cost	
Installation (incl. labour) - CCTV surveillance	included in equipment cost for mast	
Installation (incl. labour) - infrared perimeter protection beams	included in equipment cost	
Installation (incl. labour) - cabling	included in construction and equipment cost	
BACK OFFICE		
Installation and configuration - back office software	SUM = 20% capital expenditure (CAPEX)	5,000
Installation – back-office hardware	included in equipment cost	
Installation - ADSL	SUM	10,000
GENERAL		
Ground staff training (one day)	SUM	1,000
Back-office staff training (one day)	SUM	1,000
Pre-launch marketing	not included	
Website development	SUM	3,000

10.1.1 OPERATING AND MAINTENANCE UNIT COSTS

Operating and maintenance costs are recurring costs that cannot be related to any tangible assets. In this research, these costs are expressed per annum and include the costs relating to staffing, bicycle and station maintenance, bicycle redistribution and the general back-office operating expenses (see ***Table 10.4***). A number of other operating and maintenance costs will present themselves once the scheme is in place. These include, for example, cleaning and marketing beyond social media, but they were not accounted for in the cost analysis. Furthermore, improved visible policing, law enforcement and security programmes were also not included, as they are seen to be initiatives that are not exclusive to the bicycle-sharing scheme; their costs should be carried by the municipality.

A greater initial capital investment generally gives rise to a decrease in recurring costs, and vice versa, which is again why a sub-standard design was taken to be unthinkable.

The cost for staffing varies for the different modifications, as will be described in ***Section 10.3***.

As mentioned in ***Section 9.5.3***, the annual maintenance cost of a bicycle is dependent on the use (or abuse) of the bicycle. The value of ZAR 1,000 was estimated from Flandria Cycle's minimum labour tariff list (see ***Appendix I.1***). The assumed annual replacement of 5% of the bicycle fleet accounts for the theft of bicycles, as well as bicycles that are damaged beyond repair. These are to be kept in storage in the storage container, so that immediate fleet replacements can be made.

Table 10.4: A breakdown of the operating and maintenance costs (unit prices) for the bicycle-sharing system.

Cost item	Unit	Rate in ZAR
Staffing		
Staff – Ground	per annum	38,500 to 60,000
Staff – Maintenance (medium to high)	outsourced	
Staff – Back-office (control, marketing and customer care service centre)	per annum	84,000 to 210,000
Maintenance of Bicycles and Docking Stations		
Maintenance of bicycles	per bicycle per annum	1,000
Replacement of bicycles (5%)	no.	4,000
Maintenance at Drop-and-Go and Park-and-Ride	per station per annum	10,000
Maintenance at in-town docking stations	per station per annum	5,000
Redistribution		
Vehicle running cost of redistribution truck (10% of capital cost)	per annum	26,000
Back Office System		
ADSL 10Mb/s uncapped.	per annum	192,000
Marketing and Customer Service	using free social media	
Insurance	not included	

10.2 SERVICE LIFE OF THE FACILITY AND EQUIPMENT

The service life of the system over which costs and benefits were evaluated was defined in ***Section 4.5.2.5.4*** to be 15 years. The parking lot facilities were taken to have a life equal to this. All other equipment, except for the maintenance / redistribution truck (service life of 15 years) was taken to have a service life of 7 to 8 years, which meant a complete replacement once during the 15 years. Although a forklift replacement is not typically applied in reality, for the purpose of this research project, all equipment was assumed to require replacement at the end of year 7. Implementation costs were not accounted for again during this replacement procedure.

10.3 COST MODIFICATIONS

For the cost analysis, the costs were split into:

1. fixed costs – expenses that stay the same regardless of the number of users,
2. variable costs – expenses that are dependent on the number of users.

The costs of the following system components were identified as the variable costs:

- standard bicycle,
- QR code,
- GPS tracking,
- bicycle trailer (provided for 20% of the users),
- front carrier,
- standard docking stand,
- electronic lock,
- QR code,
- installation (incl. labour) - QR codes onto bicycles, trailers and electronic locks,
- maintenance of bicycles, and
- replacement of bicycles (5%)

Although the electric cabling is actually also a variable cost, the different metre lengths required for a different number of docks per station, has an insignificant effect on the total variable costs, and thus a fixed cost related to an average of 200 m of cabling per station was assumed. The cost of the supply of electricity to the Drop-and-Go and Park-and-Ride was already encompassed in the construction costs; the additional cabling was thus only required to power the equipment. It was assumed that electric wiring is readily available at the in-town stations and that a connection to this wiring can be easily made. The maintenance at the Drop-and-Go and Park-and-Ride, as well as the in-town stations was also taken to be a fixed cost.

The costs were analysed per scenario as a PWOC for the 15 years of service. This meant that the costs for varying combinations of the scheme-size (variable costs) and operational-model (fixed costs) modifications were analysed. To do this, both the variable and fixed operating and maintenance costs had to be converted from annual expenses to a PWOC that represents these costs as a total sum over the full 15 years. It was assumed that the number of users will increase at the same annual growth rate as defined for the null alternative, namely 3%. Because this rate is the same as the discount rate, the additional annual PWOC that arose due to growth, was the same for every year of the service life.

The results are shown in ***Table 10.5*** (see files on the attached CD for the full calculation sheets). The totals include the additional costs linked to the annual growth over the 15 years, as well as the replacement costs (for the both the fleet in year 0 and the additional fleet that is expected to be required in the first 7 years).

For all the phase-1 scenarios (bicycle-sharing for school learners only), the ground-staff job should not take longer than one to two hour/s a day to do. It could be considered to employ a student for this job, who works in the evening. He / she has to merely do a quick quality-control check of all the bicycles and redistribute the bicycles from the school stations back to the Drop-and-Go. One back-office staff member is required who takes control of the system, provides user assistance and to whom malfunctions are to be reported. On a day-to-day basis, the job is not seen to be very time-consuming.

Table 10.5: Results of the cost analysis: total PWOC per scenario over the service life of 15 years.

Scheme size modification combination	fleet size in year 0	PWOC - variable total in ZAR	Operational model modification	PWOC - fixed total in ZAR	Scenarios with this combination	Total cost of scenarios in ZAR
B2	415	18,681,159	B9 - PL 1	9,657,730	S2, S8, S14, S20, S26, S32, S38, S44, S50	28,338,889
	415	16,480,969	M15 - PL 1	8,820,988	S5, S11, S17, S23, S29, S35, S41, S47, S53	25,301,957
B2, B3	983	44,249,589	B9 - PL 1, 3	22,392,135	S3, S9, S15, S21, S27, S33, S39, S45, S51	66,641,724
	983	38,372,596	M15 - PL 1, 3	20,689,346	S6, S12, S18, S24, S30, S36, S42, S48, S54	59,061,942
B2, B3, B4	1262	56,808,730	B9 - PL 1, 2, 3	24,957,149	S4, S10, S16, S22, S28, S34, S40, S46, S52	81,765,879
	1262	49,125,701	M15 - PL 1, 2, 3	23,071,946	S7, S13, S19, S25, S31, S37, S43, S49, S55	72,197,647
M1	312	14,044,631	B9 - PL 1	9,657,730	S56, S62, S68, S74, S80, S86, S92, S98, S104	23,702,360
	312	12,390,512	M15 - PL 1	8,820,988	S59, S54, S71, S77, S83, S89, S95, S101, S107	21,211,500
M1, M2	737	33,265,968	B9 - PL 1, 3	22,392,135	S57, S63, S69, S75, S81, S87, S93, S99, S105	55,658,103
	737	28,847,773	M15 - PL 1, 3	20,689,346	S60, S55, S72, S78, S84, S90, S96, S102, S108	49,537,120
M1, M2, M3	947	42,719,085	B9 - PL 1, 2, 3	24,957,149	S58, S64, S70, S76, S82, S88, S94, S100, S106	67,676,234
	947	36,941,508	M15 - PL 1, 2, 3	23,071,946	S61, S56, S73, S79, S85, S91, S97, S103, S109	60,013,454
M4	208	9,363,087	B9 - PL 1	9,657,730	S110, S116, S122, S128, S134, S140	19,020,817
	208	8,260,341	M15 - PL 1	8,820,988	S113, S119, S125, S131, S137, S143	17,081,329
M4, M5	492	22,147,302	B9 - PL 1, 3	22,392,135	S111, S117, S123, S129, S135, S141	44,539,437
	492	19,206,154	M15 - PL 1, 3	20,689,346	S114, S120, S126, S132, S138, S144	39,895,501
M4, M5, M6	631	28,449,380	B9 - PL 1, 3	22,392,135	S112, S118, S124, S130, S136, S142	50,841,515
	631	24,601,978	M15 - PL 1, 3	20,689,346	S115, S121, S127, S133, S139, S145	45,291,324

The main requirement is that this person is reachable especially during the morning and then spread-out afternoon commute. The job can easily be done in combination with another one.

For the phase-2 scenarios (bicycle-sharing also for SU students and staff), the ground-staff job is slightly more demanding, as the fleet size is larger and redistribution is to be done at the in-town campus stations before the PM commute (maybe) and also afterwards at around 6pm back to the Drop-and-Go and Park-and-Ride. The back-office job is also more permanent for phase 2 than phase 1. The job is to be done in shifts by two persons between 7am and 7pm who have overlapping shifts in the middle of the day.

In ***Chapter 13***, after the benefit-analysis results of the system are given, the results of the cost analysis (and benefit analysis) are compared to typical international values, found during the literature review.

10.4 COSTS TO THE POTENTIAL BICYCLE-SHARE USERS

As described in ***Section 4.6.2***, the costs (and benefits) to the potential bicycle-share users were only evaluated for the commuters, and only the out-of-pocket cost, i.e. the annual membership fee, was taken into account as part of the cost analysis. This is R2,500 for the scholars, and R3,000 for the SU students and staff.

11 BICYCLE-SHARING REVENUE ASSESSMENT

This chapter relates back to ***Sections 9.7*** and ***9.10.2.2***, where the membership and usage fees were proposed, and the potential advertising revenue conversed, respectively.

The scenarios for which the potential revenue were calculated, were the same as for the bicycle-sharing benefit analysis, except that the number of potential users were included in the calculations and not the vehicle-trip savings.

The total revenue for each scenario comprised four main revenue sources:

1. annual memberships (R2,500 for scholars and R3,000 for SU students and staff, per year)
2. revenue for fleet hire to tourists (R75 per bicycle per tour)
3. casual riders (R7 per trip)
4. trailer rental (R5 per day)
5. advertising (R5,000 at Drop-and-Go and Park-and-Ride, and R2,100 at campus stations, per year)

The revenues from the tourists, casual riders and trailer rental were first established per day, and then multiplied by a certain number of days in the year. It was assumed for the tourist-hire that 5% of the school fleet is hired out per day on 2 days of the week for 26 weeks in the year. For the casual riders, it was supposed that 75% of the SU fleet is rented out once a day for 200 days in the year. A fleet of trailers 20% that of the bicycle fleet was assumed to be rented out every day for 200 days in the year.

1% on the total potential revenue was calculated for bank transaction reconciliation.

A 10% increase and a 10% decrease were determined for the total potential revenue computed per scenario (B8), which resulted in modifications M13 and M14.

The results of the revenue assessment are given in ***Table 11.1*** per scenario over the service life of the system. The spreadsheets containing the detailed steps of each calculation are provided on the attached CD.

Table 11.1: Potential revenue per scenario over the service life of the system.

Scenario	no. of scholars cycling in 2020	no. of SU students cycling in 2020	no. of SU staff cycling in 2020	Membership revenue (Rand)	Tourist revenue (Rand)	Casual-rider revenue (Rand)	Trailer rental (Rand)	Advertising revenue (Rand)	Fare Structure	Total revenue for scenario (Rand)
S2, S5	415	0	0	18,675,905	1,213,934	0	1,245,060	75,000	B8	20,997,801
S3, S6	415	568	0	41,125,248	1,213,934	5,964,465	2,949,193	307,500	B8	51,044,737
S4, S7	415	568	279	53,697,575	1,213,934	8,898,008	3,787,348	382,500	B8	67,299,572
S8, S11	415	0	0	18,675,905	1,213,934	0	1,245,060	75,000	M13	23,330,889
S9, S12	415	568	0	41,125,248	1,213,934	5,964,465	2,949,193	307,500	M13	56,716,374
S10, S13	415	568	279	53,697,575	1,213,934	8,898,008	3,787,348	382,500	M13	74,777,302
S14, S17	415	0	0	18,675,905	1,213,934	0	1,245,060	75,000	M14	19,088,910
S15, S18	415	568	0	41,125,248	1,213,934	5,964,465	2,949,193	307,500	M14	46,404,306
S16, S19	415	568	279	53,697,575	1,213,934	8,898,008	3,787,348	382,500	M14	61,181,429
S20, S23 S56, S59	312	0	0	11,694,177	912,146	0	935,534	75,000	B8	13,480,689
S21, S24 S57, S60	312	427	0	30,891,756	912,146	4,479,435	2,215,373	307,500	B8	38,418,147
S22, S25 S58, S61	312	427	210	40,334,043	912,146	6,682,635	2,844,859	382,500	B8	50,644,621
S26, S29 S62, S65	312	0	0	11,694,177	912,146	0	935,534	75,000	M13	14,978,543
S27, S30 S63, S66	312	427	0	30,891,756	912,146	4,479,435	2,215,373	307,500	M13	42,686,830
S28, S31 S64, S67	312	427	210	40,334,043	912,146	6,682,635	2,844,859	382,500	M13	56,271,801
S32, S35 S68, S71	312	0	0	11,694,177	912,146	0	935,534	75,000	M14	12,255,172
S33, S36 S69, S72	312	427	0	30,891,756	912,146	4,479,435	2,215,373	307,500	M14	34,925,589
S34, S37 S70, S73	312	427	210	40,334,043	912,146	6,682,635	2,844,859	382,500	M14	46,040,565

S74, S77	233	0	0	8,738,028	681,566	0	699,042	75,000	B8	10,091,700
S75, S78	233	320	0	23,136,212	681,566	3,359,576	1,658,921	307,500	B8	28,852,338
S76, S79	233	320	158	30,230,970	681,566	5,015,020	2,131,905	382,500	B8	38,057,541
S80, S83	233	0	0	8,738,028	681,566	0	699,042	75,000	M13	11,213,000
S81, S84	233	320	0	23,136,212	681,566	3,359,576	1,658,921	307,500	M13	32,058,154
S82, S85	233	320	158	30,230,970	681,566	5,015,020	2,131,905	382,500	M13	42,286,157
S86, S89	233	0	0	8,738,028	681,566	0	699,042	75,000	M14	9,174,273
S87, S90	233	320	0	23,136,212	681,566	3,359,576	1,658,921	307,500	M14	26,229,398
S88, S91	233	320	158	30,230,970	681,566	5,015,020	2,131,905	382,500	M14	34,597,764
S38, S41 S110, S113	208	0	0	7,781,627	606,967	0	622,530	75,000	B8	8,995,263
S39, S42 S111, S114	208	284	0	20,562,624	606,967	2,982,233	1,474,597	307,500	B8	25,674,581
S40, S43 S112, S115	208	284	140	26,874,871	606,967	4,455,090	1,895,413	307,500	B8	33,798,443
S44, S47 S116, S119	208	0	0	7,781,627	606,967	0	622,530	75,000	M13	9,994,737
S45, S48 S117, S120	208	284	0	20,562,624	606,967	2,982,233	1,474,597	307,500	M13	28,527,312
S46, S49 S118, S121	208	284	140	26,874,871	606,967	4,455,090	1,895,413	307,500	M13	37,553,826
S50, S53 S122, S125	208	0	0	7,781,627	606,967	0	622,530	75,000	M14	8,177,512
S51, S54 S123, S126	208	284	0	20,562,624	606,967	2,982,233	1,474,597	307,500	M14	23,340,528
S52, S55 S124, S127	208	284	140	26,874,871	606,967	4,455,090	1,895,413	307,500	M14	30,725,857
S92, S95 S128, S131	155	0	0	5,825,352	454,377	0	466,028	75,000	B8	6,752,550
S93, S96 S129, S132	155	213	0	15,424,142	454,377	2,239,718	1,105,947	307,500	B8	19,336,367
S94, S97 S130, S133	155	213	104	20,119,202	454,377	3,335,232	1,418,951	307,500	B8	25,378,909

S98, S101 S134, S137	155	0	0	5,825,352	454,377	0	466,028	75,000	M13	7,502,834
S99, S102 S135, S138	155	213	0	15,424,142	454,377	2,239,718	1,105,947	307,500	M13	21,484,852
S100, S103 S136, S139	155	213	104	20,119,202	454,377	3,335,232	1,418,951	307,500	M13	28,198,788
S104, S107 S140, S143	155	0	0	5,825,352	454,377	0	466,028	75,000	M14	6,138,682
S105, S108 S141, S144	155	213	0	15,424,142	454,377	2,239,718	1,105,947	307,500	M14	17,578,516
S106, S109 S142, S145	155	213	104	20,119,202	454,377	3,335,232	1,418,951	307,500	M14	23,071,736

12 BICYCLE-SHARING BENEFITS ANALYSIS

The benefits of the theoretical bicycle-sharing scheme for Stellenbosch were calculated as described in the various subsections of ***Section 4.7***. The travel costs were calculated per scenario of the bicycle-sharing alternative, and a benefit only arose when these costs were then subtracted from the travel costs of the null alternative. All the costs relate to the AM-peak hour for 200 days in the year of 2020 – the year of the system launch. It is explained in ***Section 12.8*** why the benefits were not calculated for the other years.

The benefits for the SU students and staff past the study area were not included, because there were too many route-options to consider. This is a conservative approach, for some unknown further benefits are felt there at no additional cost. The extent of these benefits on individual routes is questionable, though, since the vehicles spread out beyond the exit points of the study area and mix with other traffic.

Bicycle-sharing schemes typically take a number of years to 'mature' to their full demand potential. In this research project, the identified number of potential users were all assumed to take up cycling at the time of the launch, but the modifications of ridership do account for different levels of uptake.

12.1 BICYCLE-SHARING O-D MATRICES

As for the null alternative, a new O-D matrix had to be created for every possible combination of modifications. These combinations relate to the scheme-size and ridership modifications defined in ***Table 4.14*** in ***Section 4.5.2.2***. For the bicycle-sharing alternative, the 2020-null-alternative O-D matrix was taken as the base for all these combinations, and a unique number of vehicle trips was then subtracted from specific O-D pairs of each matrix. Looking at the matrix for the 2020 null alternative (see ***Appendix F.2***, ***Table F.7***), there were limits as to how many trips could be subtracted from an O-D pair.

The total number of potential users for the three road-user groups were given in ***Chapter 8***. For the benefit analysis it was the potential vehicle-trip savings that were required as the main input, and not the number of potential users themselves. The number of potential users only played a role in the benefit calculation relating to travel-time costs. ***Table 12.1*** presents the 2020 number of vehicle-trip savings that were applied for each combination of modifications, assuming a 3% growth from 2015.

For the scholars, it was assumed that all vehicles turn right into Van Reede Rd from the R44. The results of the travel survey for the SU students and staff revealed which way the respondents drive through the network once they have reached the R44 / Van Reede intersection. After the potential users had been identified, these travel patterns were analysed. A summary of the results is given in ***Table 12.2***. Referring back to ***Chapter 5***, ***Figure E.7*** in ***Appendix E.6*** lists the paths per O-D pair for the Visum model after equilibrium assignment had been completed. The paths are as follows:

- from zone 1 to 7: via the R44
- from zone 1 to 9 and 10: via the R44 and Dorp St
- from zone 1 to 12: via Van Reede Rd, Vrede Rd and Piet Retief Rd into Noordwal-Wes Rd
- from zone 1 to 13: via Van Reede Rd, Vrede Rd and Piet Retief Rd into Suidwal Rd

Table 12.1: Number of vehicle-trip savings per scenario for 2020 AM-peak hour period.

Scenario	Scheme size	Ridership	Vehicle trip savings in 2020		
			Scholars	SU students	SU staff
S2, S5, S8, S11, S14, S17	B2	B5	308	0	0
S3, S6, S9, S12, S15, S18	B2, B3	B5, B6	308	493	0
S4, S7, S10, S13, S16, S19	B2, B3, B4	B5, B6, B7	308	493	261
S20, S23, S26, S29, S32, S35	B2	M7	232	0	0
S56, S59, S62, S65, S68, S71	M1	B5			
S21, S24, S27, S30, S33, S36	B2, B3	M7, M8	232	370	0
S57, S60, S63, S66, S69, S72	M1, M2	B5, B6			
S22, S25, S28, S31, S34, S37	B2, B3, B4	M7, M8, M9	232	370	196
S58, S61, S64, S67, S70, S73	M1, M2, M3	B5, B6, B7			
S74, S77, S80, S83, S86, S89	M1	M7	174	0	0
S75, S78, S81, S84, S87, S90	M1, M2	M7, M8	174	277	0
S76, S79, S82, S85, S88, S91	M1, M2, M3	M7, M8, M9	174	277	147
S38, S41, S44, S47, S50, S53	B2	M10	154	0	0
S110, S113, S116, S119, S122, S125	M4	B5			
S39, S42, S45, S48, S51, S54	B2, B3	M10, M11	154	247	0
S111, S114, S117, S120, S123, S126	M4, M5	B5, B6			
S40, S43, S46, S49, S52, S55	B2, B3, B4	M10, M11, M12	154	247	131
S112, S115, S118, S121, S124, S127	M4, M5, M6	B5, B6, B7			
S92, S95, S98, S101, S104, S107	M1	M10	116	0	0
S128, S131, S134, S137, S140, S143	M4	M7			
S93, S96, S99, S102, S105, S108	M1, M2	M10, M11	116	184	0
S129, S132, S135, S138, S141, S144	M4, M5	M7, M8			
S94, S97, S100, S103, S106, S109	M1, M2, M3	M10, M11, M12	116	184	97
S130, S133, S136, S139, S142, S145	M4, M5, M6	M7, M8, M9			

Table 12.2: Proportion of potential users per travel route from zone 1 through the network.

To-zone	Route	SU students	SU staff
7	via R44	0.308	0.2205
9 and 10	via R44 and Dorp St	0.3618	0.2695
9 and 10	via Van Reede Rd and Piet Retief St	0.132	0.1734
12	via Van Reede Rd and Piet Retief St	0.132	0.1683
13	via Van Reede Rd and Piet Retief St	0.066	0.1783

Beginning with the scholars, it had to be remembered that the parents of the potential users return home after dropping off their children at the respective school/s, which meant that vehicle trips also had to be subtracted from the reverse direction (to zone 1 instead of from zone 1 only). To be conservative, trips were subtracted from the O-D pair 1-15 first (Rhenish Girls' High School, shortest distance). The limit of vehicle trips for this O-D pair was 297, but for the return trip only 82 vehicles. This meant that for the inbound trips destined to zone 15, a number of vehicle trips greater than 82 first travelled from zone 15 to zone 14 (Bloemhof Girls' High School) before returning home from there. The respective subtractions for this occurrence were made. Once the outbound limit for zone 14 was also reached, trips were subtracted from the direct path to / from zone 13 (Paul Roos Gymnasium). As the last option, vehicles were assumed to travel to zone 13 via zones 14 and 15 before making their way back. The resulting O-D matrices for the scenarios only encompassing scholars as potential users are given in ***Appendix J.1***.

For the SU students and staff, the subtraction procedure was dealt with in much the same way, just for other zones, and with the difference that there were no return trips (see ***Appendix J.1***). The O-D matrices created for the benefit analysis are also provided in a spreadsheet on the attached CD, where all subtractions can be viewed. As a general rule, trips were subtracted from zone 10 first before moving on to zone 9, and trips made from zone 1 to zone 9 and 10 via Piet Retief, were taken to be made via zone 15 (because there is no direct path for these O-D pairs in the model). All trip subtractions were made from O-D pairs with an origin in zone 1, and the total trip subtractions for the SU users were then added again to the 1-2 O-D pair, since the Park-and-Ride is located in zone 2. Consequently, it was assumed that the delay at the R44 / Van Reede intersection for the bicycle-sharing alternative would only be reduced as a result of school-trip savings. When no more trips could be subtracted from zone 1, the trips were removed from the O-D pairs with an origin in zone 2, and these trips were then not added to the 1-2 pair. Trips were also taken to be made via zone 15 and 14 when all other limits had been reached.

12.2 VMT, VHT AND MEAN SYSTEM SPEED – MOBILITY BENEFITS

Once all the new O-D matrices had been created, the new delays at each of the affected intersections could be determined per scenario. With reference to the respective new O-D matrices, this was done by subtracting the particular trips from each of the concerned turn-movement volumes. A summary of these new delays, per combination of the modifications, and the detailed intersection ICA reports are provided on the attached CD.

The new delays on the links were calculated as described in ***Section 4.7.9***, i.e. multiplying the ratio of new volumes and the 2020-null-alternative volumes (taken to a power of the VD-function *b* parameter) by the total link-delay determined for the null alternative.

Table 12.3 shows the calculated 2020 VMT, VHT and mean system speed per bicycle-sharing scenario (see files on attached CD for full VMT and VHT matrices). Referring back to ***Section 6.2.1***, the VMT, VHT and mean system speed for the 2020 null alternative were 15,349 km, 1,522 h and 10.09 km/h, respectively. The benefits achieved for these parameters are revealed in ***Table 12.4***. As expected, the scenarios with all identified potential users (for all three road-user groups) cycling, resulted in the highest new mean system speed, namely 16.01 km/h. All the mean system speeds, including those for the null alternative seem very low, but it must be remembered that the waiting time at the intersections, i.e. a speed of 0 km/h faced in the case of the red phase at a signalised intersection, is included in this average. The effect such small differences in mean system speed have on travel costs (even for a small network such as that studied in this research project) are disclosed in the subsequent subsection.

Table 12.3: 2020 AM VMT, VHT and mean system speed per bicycle-sharing scenario.

Scenarios	2020 AM VMT (km)	2020 AM VHT (h)	2020 AM mean system speed (km/h)
S2, S5, S8, S11, S14, S17	13,812.54	1,050.87	13.14
S20, S23, S26, S29, S32, S35, S56, S59, S62, S65, S68, S71	14,227.95	1,162.31	12.24
S38, S41, S44, S47, S50, S53, S110, S113, S116, S119, S122, S125	14,654.33	1,258.79	11.64
S74, S77, S80, S83, S86, S89	14,545.21	1,237.09	11.76
S92, S95, S98, S101, S104, S107, S128, S131, S134, S137, S140, S143	14,855.40	1,306.49	11.37
S3, S6, S9, S12, S15, S18	13,113.67	893.89	14.67
S21, S24, S27, S30, S33, S36, S57, S60, S63, S66, S69, S72	13,700.12	1,026.41	13.35
S39, S42, S45, S48, S51, S54, S111, S114, S117, S120, S123, S126	14,298.82	1,144.15	12.50
S75, S78, S81, S84, S87, S90	14,148.59	1,115.21	12.69
S93, S96, S99, S102, S105, S108, S129, S132, S135, S138, S141, S144	14,590.01	1,207.24	12.09
S4, S7, S10, S13, S16, S19	12,713.89	794.04	16.01
S22, S25, S28, S31, S34, S37, S58, S61, S64, S67, S70, S73	13,457.81	983.33	13.69
S40, S43, S46, S49, S52, S55, S112, S115, S118, S121, S124, S127	14,117.84	1,114.62	12.67
S76, S79, S82, S85, S88, S91	13,939.23	1,083.61	12.86
S94, S97, S100, S103, S106, S109, S130, S133, S136, S139, S142, S145	14,450.99	1,180.00	12.25

Table 12.4: 2020 AM mobility benefits for the bicycle-sharing scenario.

Scenarios	2020 AM decrease in VMT (km)	2020 AM decrease in VHT (h)	2020 AM increase in mean system speed (km/h)
S2, S5, S8, S11, S14, S17	1,537	471	3.05
S20, S23, S26, S29, S32, S35, S56, S59, S62, S65, S68, S71	1,121	359	2.15
S38, S41, S44, S47, S50, S53, S110, S113, S116, S119, S122, S125	695	263	1.55
S74, S77, S80, S83, S86, S89	804	285	1.67
S92, S95, S98, S101, S104, S107, S128, S131, S134, S137, S140, S143	494	215	1.28
S3, S6, S9, S12, S15, S18	2,236	628	4.58
S21, S24, S27, S30, S33, S36, S57, S60, S63, S66, S69, S72	1,649	495	3.26
S39, S42, S45, S48, S51, S54, S111, S114, S117, S120, S123, S126	1,051	378	2.41
S75, S78, S81, S84, S87, S90	1,201	407	2.60
S93, S96, S99, S102, S105, S108, S129, S132, S135, S138, S141, S144	759	315	2.00
S4, S7, S10, S13, S16, S19	2,636	728	5.92
S22, S25, S28, S31, S34, S37, S58, S61, S64, S67, S70, S73	1,892	538	3.60
S40, S43, S46, S49, S52, S55, S112, S115, S118, S121, S124, S127	1,232	407	2.58
S76, S79, S82, S85, S88, S91	1,410	438	2.77
S94, S97, S100, S103, S106, S109, S130, S133, S136, S139, S142, S145	898	342	2.16

12.3 SAVINGS IN ROAD USER COSTS

For the next subsections, travel costs are first given for the bicycle-sharing alternative and then the cost benefits (in comparison to the null alternative) are shared. The reader is reminded again that the road user costs refer to VOCs, travel-time costs and accident costs, and not to the per-road-user costs.

12.3.1 SAVED VEHICLE OPERATING COSTS

Using the mean system speed and the VMT, the total operating costs were calculated as explained in ***Section 4.7.3.1*** and done for the null alternative. The results, per scenario, are shown in ***Table 12.5***. Since the VOCs for the cyclists is zero, these travel costs were then directly subtracted from the cost calculated for the null alternative: R 26,754,623. The resulting 2020 VOC savings are listed in ***Table 12.6***.

Table 12.5: 2020 AM VOCs calculated for the remaining road users per bicycle-sharing scenario.

Scenarios	2020 AM VOC (ZAR)
S2, S5, S8, S11, S14, S17	21,204,987
S20, S23, S26, S29, S32, S35, S56, S59, S62, S65, S68, S71	22,572,630
S38, S41, S44, S47, S50, S53, S110, S113, S116, S119, S122, S125	23,807,614
S74, S77, S80, S83, S86, S89	23,518,906
S92, S95, S98, S101, S104, S107, S128, S131, S134, S137, S140, S143	24,408,495
S3, S6, S9, S12, S15, S18	19,168,543
S21, S24, S27, S30, S33, S36, S57, S60, S63, S66, S69, S72	20,885,910
S39, S42, S45, S48, S51, S54, S111, S114, S117, S120, S123, S126	22,466,875
S75, S78, S81, S84, S87, S90	22,076,360
S93, S96, S99, S102, S105, S108, S129, S132, S135, S138, S141, S144	23,286,444
S4, S7, S10, S13, S16, S19	17,897,559
S22, S25, S28, S31, S34, S37, S58, S61, S64, S67, S70, S73	20,286,257
S40, S43, S46, S49, S52, S55, S112, S115, S118, S121, S124, S127	22,045,134
S76, S79, S82, S85, S88, S91	21,611,496
S94, S97, S100, S103, S106, S109, S130, S133, S136, S139, S142, S145	22,921,600

Table 12.6: 2020 AM VOC savings calculated per bicycle-sharing scenario.

Scenarios	2020 AM VOC saving (ZAR)
S2, S5, S8, S11, S14, S17	5,549,636
S20, S23, S26, S29, S32, S35, S56, S59, S62, S65, S68, S71	4,181,993
S38, S41, S44, S47, S50, S53, S110, S113, S116, S119, S122, S125	2,947,009
S74, S77, S80, S83, S86, S89	3,235,716
S92, S95, S98, S101, S104, S107, S128, S131, S134, S137, S140, S143	2,346,128
S3, S6, S9, S12, S15, S18	7,586,080
S21, S24, S27, S30, S33, S36, S57, S60, S63, S66, S69, S72	5,868,712
S39, S42, S45, S48, S51, S54, S111, S114, S117, S120, S123, S126	4,287,748
S75, S78, S81, S84, S87, S90	4,678,263
S93, S96, S99, S102, S105, S108, S129, S132, S135, S138, S141, S144	3,468,179
S4, S7, S10, S13, S16, S19	8,857,063
S22, S25, S28, S31, S34, S37, S58, S61, S64, S67, S70, S73	6,468,366
S40, S43, S46, S49, S52, S55, S112, S115, S118, S121, S124, S127	4,709,488
S76, S79, S82, S85, S88, S91	5,143,127
S94, S97, S100, S103, S106, S109, S130, S133, S136, S139, S142, S145	3,833,023

12.3.2 TRAVEL-TIME SAVINGS

The travel-time costs were computed as outlined in ***Section 4.7.3.3***, and for four modifications of VOT, as done for the null alternatives. VOT 1 to 4 were defined in ***Section 6.2.1.1***. The results for the 2020 bicycle-sharing alternative are shown per scenario in ***Table 12.7***. For VOT 1, the travel-time costs are similar in magnitude to the VOCs. For the other VOT modifications, the VOT costs are lower, but by no means insignificant.

Before these results could be subtracted from the null-alternative travel-time costs, the travel-time costs for the cyclists first had to be added to the costs listed in ***Table 12.7***. The travel-time costs for the cyclists are given in ***Table 12.8***, taking into account their individual VOTs. Since the travel time is shorter for the cyclists (see ***Section 12.8***), the VOT is lower, and, of course, also because the VOT of the SU students is lower than the average VOT applied in the travel-time costs for the remaining road users. As said before, the VOT for the scholars is zero, and therefore no travel-time costs arose for the cyclists of this road-user group. The total travel-time savings are presented in ***Table 12.9***.

Table 12.7: 2020 AM travel-time costs for the remaining road users, calculated per bicycle-sharing scenario.

Scenarios	2020 AM travel-time cost for the remaining road users (ZAR)			
	VOT 1	VOT 2	VOT 3	VOT 4
S2, S5, S8, S11, S14, S17	18,915,728	9,457,864	15,132,583	7,566,291
S20, S23, S26, S29, S32, S35, S56, S59, S62, S65, S68, S71	20,921,646	10,460,823	16,737,317	8,368,658
S38, S41, S44, S47, S50, S53, S110, S113, S116, S119, S122, S125	22,658,300	11,329,150	18,126,640	9,063,320
S74, S77, S80, S83, S86, S89	22,267,560	11,133,780	17,814,048	8,907,024
S92, S95, S98, S101, S104, S107, S128, S131, S134, S137, S140, S143	23,516,810	11,758,405	18,813,448	9,406,724
S3, S6, S9, S12, S15, S18	16,090,069	8,045,034	12,872,055	6,436,028
S21, S24, S27, S30, S33, S36, S57, S60, S63, S66, S69, S72	18,475,382	9,237,691	14,780,305	7,390,153
S39, S42, S45, S48, S51, S54, S111, S114, S117, S120, S123, S126	20,594,624	10,297,312	16,475,699	8,237,850
S75, S78, S81, S84, S87, S90	20,073,788	10,036,894	16,059,031	8,029,515
S93, S96, S99, S102, S105, S108, S129, S132, S135, S138, S141, S144	21,730,245	10,865,122	17,384,196	8,692,098
S4, S7, S10, S13, S16, S19	14,292,737	7,146,368	11,434,189	5,717,095
S22, S25, S28, S31, S34, S37, S58, S61, S64, S67, S70, S73	17,699,991	8,849,996	14,159,993	7,079,996
S40, S43, S46, S49, S52, S55, S112, S115, S118, S121, S124, S127	20,063,154	10,031,577	16,050,523	8,025,261
S76, S79, S82, S85, S88, S91	19,504,978	9,752,489	15,603,983	7,801,991
S94, S97, S100, S103, S106, S109, S130, S133, S136, S139, S142, S145	21,239,945	10,619,973	16,991,956	8,495,978

Table 12.8: 2020 AM travel-time costs for the cyclists.

Scenarios	2020 travel-time cost for the cyclists (ZAR)		
	VOT SU students	VOT 1 SU staff	VOT 2 SU staff
S3, S6, S9, S12, S15, S18	100,800	-	-
S21, S24, S27, S30, S33, S36, S57, S60, S63, S66, S69, S72	75,703	-	-
S39, S42, S45, S48, S51, S54, S111, S114, S117, S120, S123, S126	50,400	-	-
S75, S78, S81, S84, S87, S90	56,777	-	-
S93, S96, S99, S102, S105, S108, S129, S132, S135, S138, S141, S144	37,851	-	-
S4, S7, S10, S13, S16, S19	100,800	371,829	185,914
S22, S25, S28, S31, S34, S37, S58, S61, S64, S67, S70, S73	75,703	279,257	139,629
S40, S43, S46, S49, S52, S55, S112, S115, S118, S121, S124, S127	50,400	186,686	93,343
S76, S79, S82, S85, S88, S91	56,777	209,829	104,914
S94, S97, S100, S103, S106, S109, S130, S133, S136, S139, S142, S145	37,851	138,857	69,429

12.3.3 ACCIDENT-COST SAVINGS

On the attached CD, the 2010 to 2014 recorded accident data for the R44 between Jamestown and Dorp St are given. A summary of this data for accidents that occurred within and around the AM-peak hour is shared in ***Table 12.10***. For all these accidents, the road surface quality, the road marking condition, the road sign condition and road sign visibility were good. Of these accidents, only Accident 2 occurred within the study area. It is, in fact, the only accident to have occurred in the study area during the hours of cycling, incl. the PM commute, and as for almost all of the recorded accidents, the severity was damage-only.

So, even if it was assumed that one damage-only accident would be prevented every 5 years, the total accident-cost-saving would come to 3 x R47,200 = R141,600. In relation to the VOC and travel-time savings, these accident-cost savings will contribute little to the final outcome of benefits. Also, because no accident data was available for links other than the R44, it was then rather assumed that the cost of the number of prevented traffic accidents resulting in injury or damage only, is equal to the additional cycling accident costs that may be incurred as a result of a higher bicycle modal share.

There is also no guarantee on the accuracy of the data, i.e. the accident records could be incomplete or incorrect, and it may be found that the accidents are freak accidents that cannot be related to any road or traffic conditions. The accuracy of the data is, for example, put into question when considering the fact that all the accidents for all the hours of the day were observed only in the inbound direction.

Table 12.9: 2020 AM total travel-time savings for the bicycle-sharing alternative.

Scenarios	2020 AM travel-time cost for the remaining road users (ZAR)			
	VOT 1	VOT 2	VOT 3	VOT 4
S2, S5, S8, S11, S14, S17	8,475,847	4,237,924	6,780,677	3,390,339
S20, S23, S26, S29, S32, S35, S56, S59, S62, S65, S68, S71	6,469,929	3,234,965	5,175,943	2,587,972
S38, S41, S44, S47, S50, S53, S110, S113, S116, S119, S122, S125	4,733,275	2,366,638	3,786,620	1,893,310
S74, S77, S80, S83, S86, S89	5,124,015	2,562,008	4,099,212	2,049,606
S92, S95, S98, S101, S104, S107, S128, S131, S134, S137, S140, S143	3,874,765	1,937,383	3,099,812	1,549,906
S3, S6, S9, S12, S15, S18	11,200,706	5,549,954	8,940,405	4,419,802
S21, S24, S27, S30, S33, S36, S57, S60, S63, S66, S69, S72	8,840,490	4,382,394	7,057,252	3,490,774
S39, S42, S45, S48, S51, S54, S111, S114, S117, S120, S123, S126	6,746,551	3,348,076	5,387,161	2,668,380
S75, S78, S81, S84, S87, S90	7,261,010	3,602,117	5,797,452	2,870,338
S93, S96, S99, S102, S105, S108, S129, S132, S135, S138, S141, S144	5,623,479	2,792,815	4,491,213	2,226,681
S4, S7, S10, S13, S16, S19	12,440,295	5,890,877	9,820,528	4,580,992
S22, S25, S28, S31, S34, S37, S58, S61, S64, S67, S70, S73	9,196,995	4,351,203	7,258,678	3,382,045
S40, S43, S46, S49, S52, S55, S112, S115, S118, S121, S124, S127	6,997,992	3,333,782	5,532,308	2,600,940
S76, S79, S82, S85, S88, S91	7,515,077	3,571,779	5,937,757	2,783,119
S94, S97, S100, S103, S106, S109, S130, S133, S136, S139, S142, S145	5,905,493	2,829,678	4,675,167	2,214,515

Table 12.10: 2010 to 2014 AM accident records for the R44 between Jamestown and Dorp St.

	Accident 1	Accident 2	Accident 3	Accident 4	Accident 5
X coordinate	18.8447834	18.85510027	18.84941505	18.85438177	18.84730913
Y coordinate	-33.96742007	-33.95137895	-33.96385553	-33.95728848	-33.96506347
Accident Type	Sideswipe - same direction	Head/Rear end	Sideswipe - same direction	Sideswipe - same direction	Sideswipe - opposite direction
Date	2014/09/01	2014/02/20	2014/02/18	2014/02/18	2012/07/18
Day	MONDAY	THURSDAY	TUESDAY	TUESDAY	WEDNESDAY
Time	08:00:00 AM	07:00:00 AM	08:15:00 AM	07:40:00 AM	08:20:00 AM
Junction Type	Not at junction	Not at junction	Not at junction	Not at junction	Not at junction
Light	Daylight	Daylight	Daylight	Daylight	Daylight
Fatalities	0	0	0	0	0
Not Injured	1	2	2	1	1
Pedestrians	0	0	0	0	0
Seriously injured	0	0	0	0	0
Slightly Injured	0	0	0	1	0
Number of Vehicles	1	2	2	2	1
Obstruction Type	None	None	None	None	None
Road Direction	Straight	Straight	Straight	Straight	Straight
Road Surface Condition	Dry	Dry	Dry	Dry	Dry
Specified Cause	Cut in front of other	Insufficient following distance	Entered traffic while unsafe	Bypass distance too close	Bypass distance too close
Speed Limit	100	80	100	80	100
Weather Conditions	Clear	Overcast	Clear	Clear	Clear
Control Type	Not at junction	Not at junction	Not at junction	Not at junction	Pedestrian crossing

12.4 SAVINGS IN EXTERNAL COSTS – CO_2 EMISSIONS

The CO_2 emissions for the bicycle-sharing alternative were calculated as delineated in ***Section 4.7.6***, and as done for the null alternative. The 2020 AM fuel consumption, CO_2 emissions and CO_2-emission costs are given in ***Table 12.11*** per scenario of the bicycle-sharing alternative. ***Table 12.12*** then gives the savings related to this external cost. As also mentioned in ***Section 6.2.4*** for the null alternative, the CO_2 emission costs are almost insignificant compared to the other savings calculated. What actual impact these tonnes of CO_2 have on the environment, lay beyond the scope of this research project.

Table 12.11: 2020 AM fuel consumption, CO_2 emissions and CO_2 emission costs for the remaining road users of the bicycle-sharing alternative, per scenario.

Scenario	2020 AM fuel consumption (l/100km)	2020 AM CO_2 emissions (t)	2020 AM cost of CO_2 emissions (ZAR)
S2, S5, S8, S11, S14, S17	19.25	6.65	798.39
S20, S23, S26, S29, S32, S35, S56, S59, S62, S65, S68, S71	20.20	7.19	862.64
S38, S41, S44, S47, S50, S53, S110, S113, S116, S119, S122, S125	20.89	7.66	919.18
S74, S77, S80, S83, S86, S89	20.75	7.55	906.22
S92, S95, S98, S101, S104, S107, S128, S131, S134, S137, S140, S143	21.23	7.89	946.83
S3, S6, S9, S12, S15, S18	17.90	5.87	704.58
S21, S24, S27, S30, S33, S36, S57, S60, S63, S66, S69, S72	19.06	6.53	783.79
S39, S42, S45, S48, S51, S54, S111, S114, S117, S120, S123, S126	19.92	7.12	854.92
S75, S78, S81, S84, S87, S90	19.72	6.98	837.43
S93, S96, S99, S102, S105, S108, S129, S132, S135, S138, S141, S144	20.37	7.44	892.26
S4, S7, S10, S13, S16, S19	16.89	5.37	644.79
S22, S25, S28, S31, S34, S37, S58, S61, S64, S67, S70, S73	18.74	6.31	757.18
S40, S43, S46, S49, S52, S55, S112, S115, S118, S121, S124, S127	19.74	6.97	836.53
S76, S79, S82, S85, S88, S91	19.53	6.81	817.41
S94, S97, S100, S103, S106, S109, S130, S133, S136, S139, S142, S145	20.19	7.30	875.89

Table 12.12: 2020 AM economic savings in fuel consumption, CO2 emissions and CO2 emission costs for the bicycle-sharing alternative, per scenario.

Scenario	2020 AM saving in fuel consumption (l/100km)	2020 AM saving in CO_2 emissions (t)	2020 AM saving in cost of CO_2 emissions (ZAR)
S2, S5, S8, S11, S14, S17	3.80	2.20	263.76
S20, S23, S26, S29, S32, S35, S56, S59, S62, S65, S68, S71	2.85	1.66	199.51
S38, S41, S44, S47, S50, S53, S110, S113, S116, S119, S122, S125	2.16	1.19	142.97
S74, S77, S80, S83, S86, S89	2.30	1.30	155.93
S92, S95, S98, S101, S104, S107, S128, S131, S134, S137, S140, S143	1.82	0.96	115.32
S3, S6, S9, S12, S15, S18	5.15	2.98	357.57
S21, S24, S27, S30, S33, S36, S57, S60, S63, S66, S69, S72	3.99	2.32	278.36
S39, S42, S45, S48, S51, S54, S111, S114, S117, S120, S123, S126	3.13	1.73	207.23
S75, S78, S81, S84, S87, S90	3.33	1.87	224.72
S93, S96, S99, S102, S105, S108, S129, S132, S135, S138, S141, S144	2.68	1.41	169.89
S4, S7, S10, S13, S16, S19	6.16	3.48	417.36
S22, S25, S28, S31, S34, S37, S58, S61, S64, S67, S70, S73	4.31	2.54	304.97
S40, S43, S46, S49, S52, S55, S112, S115, S118, S121, S124, S127	3.31	1.88	225.62
S76, S79, S82, S85, S88, S91	3.52	2.04	244.74
S94, S97, S100, S103, S106, S109, S130, S133, S136, S139, S142, S145	2.86	1.55	186.26

12.5 HEALTH BENEFITS

The health benefits for the scenarios of the bicycle-sharing alternative were evaluated using the HEAT for cycling tool, introduced in ***Section 4.7.7***. As stated, the benefits were only determined for the SU students and staff, since the tool was developed for adult populations.

The cycling duration was determined from the average cycling distance between the Park-and-Ride and the campus docking stations (approximately 3 km), and an average cycling speed of 14 km/h. This gives a cycling duration of 12.85 min per direction, so the total cycling duration per day was taken to be 25 min. The number of cyclists varied per scenario and were applied as shown in ***Table 12.1***. The other input parameters were already defined in ***Section 4.7.7***.

Table 12.13 displays the results of the economic health-benefit analysis per scenario of the bicycle-sharing alternative. Results are given for the average and present-worth annual health benefits (AM and PM), as well as the present-worth value of the total benefits accumulated over the 15 years (rounded off to the nearest 1000).

The detailed HEAT for cycling output is provided in ***Appendix J.2***, per scenario of the bicycle-sharing alternative. It must be noted that the values in the reports are in fact ZAR values, not EUR values. The South African currency was just not an option to choose from in the tool.

12.6 TOTAL-COST SAVINGS

In this subsection, all the cost savings presented in the chapter are brought together and presented as one total cost saving for the scenarios of the bicycle-sharing alternative. One distinction is, however, still made between total travel costs and total costs. The total travel costs include the road user costs and environmental costs, but exclude the costs linked to the health benefits; the total costs include these health benefits.

The total 2020 AM travel costs for the bicycle-sharing alternative are given per scenario in ***Table 12.14***. The total 2010 AM travel-cost savings for the bicycle-sharing alternative are disclosed in ***Table 12.15***. It was stated in ***Section 4.7.9*** that the PM-peak period was assumed to reap travel-cost savings equal to half of the AM-peak hour benefits. The values in ***Table 12.15*** were thus multiplied by 1.5 to attain the total 2020 travel-cost savings (see ***Table 12.16***).

Finally, the annual economic health benefits per scenario were added to the values in ***Table 2.16*** in order to make known the total 2020 cost savings for the bicycle-sharing alternative (see ***Table 12.17***).

Table 12.13: Economic health-benefit results for the bicycle-sharing alternative.

Scenarios	Annual health benefits (ZAR)	PW annual health benefits (ZAR)	PWOC$_{_health}$ over 15 years (ZAR)
S2, S5, S8, S11, S14, S17	-	-	-
S20, S23, S26, S29, S32, S35, S56, S59, S62, S65, S68, S71	-	-	-
S38, S41, S44, S47, S50, S53, S110, S113, S116, S119, S122, S125	-	-	-
S74, S77, S80, S83, S86, S89	-	-	-
S92, S95, S98, S101, S104, S107, S128, S131, S134, S137, S140, S143	-	-	-
S3, S6, S9, S12, S15, S18	87,000	69,000	1,037,000
S21, S24, S27, S30, S33, S36, S57, S60, S63, S66, S69, S72	65,000	52,000	780,000
S39, S42, S45, S48, S51, S54, S111, S114, S117, S120, S123, S126	43,000	35,000	518,000
S75, S78, S81, S84, S87, S90	49,000	39,000	584,000
S93, S96, S99, S102, S105, S108, S129, S132, S135, S138, S141, S144	33,000	26,000	389,000
S4, S7, S10, S13, S16, S19	130,000	103,000	1,546,000
S22, S25, S28, S31, S34, S37, S58, S61, S64, S67, S70, S73	97,000	78,000	1,163,000
S40, S43, S46, S49, S52, S55, S112, S115, S118, S121, S124, S127	65,000	52,000	774,000
S76, S79, S82, S85, S88, S91	73,000	58,000	873,000
S94, S97, S100, S103, S106, S109, S130, S133, S136, S139, S142, S145	48,000	39,000	579,000

Table 12.14: Total 2020 AM travel costs for the bicycle-sharing alternative, per scenario.

Scenario	2020 total AM travel cost (ZAR) - with VOT 1	2020 total AM travel cost (ZAR) - with VOT 2	2020 total AM travel cost (ZAR) - with VOT 3	2020 total AM travel cost (ZAR) - with VOT 4
S2, S5, S8, S11, S14, S17	40,121,514	30,663,650	36,338,368	28,772,077
S20, S23, S26, S29, S32, S35, S56, S59, S62, S65, S68, S71	43,495,138	33,034,315	39,310,809	30,942,151
S38, S41, S44, S47, S50, S53, S110, S113, S116, S119, S122, S125	46,466,833	35,137,683	41,935,173	32,871,853
S74, S77, S80, S83, S86, S89	45,787,372	34,653,592	41,333,860	32,426,836
S92, S95, S98, S101, S104, S107, S128, S131, S134, S137, S140, S143	47,926,252	36,167,847	43,222,890	33,816,166
S3, S6, S9, S12, S15, S18	35,376,162	27,331,128	32,158,149	25,722,121
S21, S24, S27, S30, S33, S36, S57, S60, S63, S66, S69, S72	39,449,916	30,212,225	35,754,839	28,364,687
S39, S42, S45, S48, S51, S54, S111, S114, S117, S120, S123, S126	43,120,777	32,823,465	39,001,852	30,764,003
S75, S78, S81, S84, S87, S90	42,216,814	32,179,920	38,202,056	30,172,541
S93, S96, S99, S102, S105, S108, S129, S132, S135, S138, S141, S144	45,061,398	34,196,276	40,715,349	32,023,251
S4, S7, S10, S13, S16, S19	32,738,244	25,376,647	29,879,697	23,947,373
S22, S25, S28, S31, S34, S37, S58, S61, S64, S67, S70, S73	38,398,845	29,386,850	34,858,847	27,616,851
S40, S43, S46, S49, S52, S55, S112, S115, S118, S121, S124, S127	42,383,548	32,243,971	38,370,917	30,237,655
S76, S79, S82, S85, S88, S91	41,426,891	31,552,516	37,525,896	29,602,019
S94, S97, S100, S103, S106, S109, S130, S133, S136, S139, S142, S145	44,366,695	33,666,494	40,118,706	31,542,499

Table 12.15: Total 2020 AM travel-cost savings for the bicycle-sharing alternative, per scenario.

Scenario	2020 total AM travel cost (ZAR) - with VOT 1	2020 total AM travel cost (ZAR) - with VOT 2	2020 total AM travel cost (ZAR) - with VOT 3	2020 total AM travel cost (ZAR) - with VOT 4
S2, S5, S8, S11, S14, S17	14,025,746	9,787,823	12,330,577	8,940,238
S20, S23, S26, S29, S32, S35, S56, S59, S62, S65, S68, S71	10,652,122	7,417,157	9,358,136	6,770,164
S38, S41, S44, S47, S50, S53, S110, S113, S116, S119, S122, S125	7,680,427	5,313,789	6,733,772	4,840,462
S74, S77, S80, S83, S86, S89	8,359,888	5,797,880	7,335,085	5,285,478
S92, S95, S98, S101, S104, S107, S128, S131, S134, S137, S140, S143	6,221,008	4,283,625	5,446,055	3,896,149
S3, S6, S9, S12, S15, S18	18,771,098	13,120,345	16,510,796	11,990,194
S21, S24, S27, S30, S33, S36, S57, S60, S63, S66, S69, S72	14,697,344	10,239,247	12,914,106	9,347,628
S39, S42, S45, S48, S51, S54, S111, S114, S117, S120, S123, S126	11,026,483	7,628,007	9,667,093	6,948,312
S75, S78, S81, S84, S87, S90	11,930,446	8,271,553	10,466,889	7,539,774
S93, S96, S99, S102, S105, S108, S129, S132, S135, S138, S141, S144	9,085,862	6,255,197	7,953,596	5,689,064
S4, S7, S10, S13, S16, S19	21,409,016	15,074,826	18,789,248	13,764,942
S22, S25, S28, S31, S34, S37, S58, S61, S64, S67, S70, S73	15,748,415	11,064,623	13,810,098	10,095,464
S40, S43, S46, S49, S52, S55, S112, S115, S118, S121, S124, S127	11,763,712	8,207,502	10,298,028	7,474,660
S76, S79, S82, S85, S88, S91	12,720,369	8,898,956	11,143,049	8,110,296
S94, S97, S100, S103, S106, S109, S130, S133, S136, S139, S142, S145	9,780,565	6,784,979	8,550,239	6,169,816

Table 12.16: Total 2020 travel-cost savings for the bicycle-sharing alternative, per scenario.

Scenario	2020 total travel cost (ZAR) - with VOT 1	2020 total travel cost (ZAR) - with VOT 2	2020 total travel cost (ZAR) - with VOT 3	2020 total travel cost (ZAR) - with VOT 4
S2, S5, S8, S11, S14, S17	21,038,619	14,681,735	18,495,866	13,410,357
S20, S23, S26, S29, S32, S35, S56, S59, S62, S65, S68, S71	15,978,183	11,125,736	14,037,204	10,155,246
S38, S41, S44, S47, S50, S53, S110, S113, S116, S119, S122, S125	11,520,641	7,970,684	10,100,658	7,260,693
S74, S77, S80, S83, S86, S89	12,539,832	8,696,820	11,002,628	7,928,217
S92, S95, S98, S101, S104, S107, S128, S131, S134, S137, S140, S143	9,331,512	6,425,438	8,169,083	5,844,224
S3, S6, S9, S12, S15, S18	28,156,647	19,680,518	24,766,194	17,985,291
S21, S24, S27, S30, S33, S36, S57, S60, S63, S66, S69, S72	22,046,016	15,358,871	19,371,159	14,021,442
S39, S42, S45, S48, S51, S54, S111, S114, S117, S120, S123, S126	16,539,725	11,442,011	14,500,640	10,422,468
S75, S78, S81, S84, S87, S90	17,895,669	12,407,330	15,700,334	11,309,661
S93, S96, S99, S102, S105, S108, S129, S132, S135, S138, S141, S144	13,628,793	9,382,796	11,930,394	8,533,596
S4, S7, S10, S13, S16, S19	32,113,524	22,612,239	28,183,872	20,647,413
S22, S25, S28, S31, S34, S37, S58, S61, S64, S67, S70, S73	23,622,623	16,596,935	20,715,147	15,143,196
S40, S43, S46, S49, S52, S55, S112, S115, S118, S121, S124, S127	17,645,568	12,311,253	15,447,042	11,211,990
S76, S79, S82, S85, S88, S91	19,080,554	13,348,434	16,714,574	12,165,444
S94, S97, S100, S103, S106, S109, S130, S133, S136, S139, S142, S145	14,670,848	10,177,469	12,825,359	9,254,724

Table 12.17: Total 2020 cost savings for the bicycle-sharing alternative, per scenario.

Scenario	2020 total travel cost (ZAR) - with VOT 1	2020 total travel cost (ZAR) - with VOT 2	2020 total travel cost (ZAR) - with VOT 3	2020 total travel cost (ZAR) - with VOT 4
S2, S5, S8, S11, S14, S17	21,038,619	14,681,735	18,495,866	13,410,357
S20, S23, S26, S29, S32, S35, S56, S59, S62, S65, S68, S71	15,978,183	11,125,736	14,037,204	10,155,246
S38, S41, S44, S47, S50, S53, S110, S113, S116, S119, S122, S125	11,520,641	7,970,684	10,100,658	7,260,693
S74, S77, S80, S83, S86, S89	12,539,832	8,696,820	11,002,628	7,928,217
S92, S95, S98, S101, S104, S107, S128, S131, S134, S137, S140, S143	9,331,512	6,425,438	8,169,083	5,844,224
S3, S6, S9, S12, S15, S18	28,243,647	19,767,518	24,853,194	18,072,291
S21, S24, S27, S30, S33, S36, S57, S60, S63, S66, S69, S72	22,111,016	15,423,871	19,436,159	14,086,442
S39, S42, S45, S48, S51, S54, S111, S114, S117, S120, S123, S126	16,582,725	11,485,011	14,543,640	10,465,468
S75, S78, S81, S84, S87, S90	17,944,669	12,456,330	15,749,334	11,358,661
S93, S96, S99, S102, S105, S108, S129, S132, S135, S138, S141, S144	13,661,793	9,415,796	11,963,394	8,566,596
S4, S7, S10, S13, S16, S19	32,243,524	22,742,239	28,313,872	20,777,413
S22, S25, S28, S31, S34, S37, S58, S61, S64, S67, S70, S73	23,719,623	16,693,935	20,812,147	15,240,196
S40, S43, S46, S49, S52, S55, S112, S115, S118, S121, S124, S127	17,710,568	12,376,253	15,512,042	11,276,990
S76, S79, S82, S85, S88, S91	19,153,554	13,421,434	16,787,574	12,238,444
S94, S97, S100, S103, S106, S109, S130, S133, S136, S139, S142, S145	14,718,848	10,225,469	12,873,359	9,302,724

12.7 BENEFITS FOR THE OTHER YEARS

The initial intention was to determine the benefits for the bicycle-sharing alternative for 2020 and then extrapolate these benefits to the other years of the service life of the system using the diurnal travel (extrapolation from one particular travel hour within the day to other travel hours of a day) and annual travel (extrapolation from a particular year of analysis to later years of the project life) measurements described in the User and Non-User benefit Analysis for Highways manual (AASHTO, 2010). It was soon realised then, however, that these measurements are only applicable to the extrapolation of the benefits experienced on the links, not the nodes.

It was then decided to manually calculate the benefits as done for the year 2020. This is, though, when the problem of peak spreading surfaced. ***Appendix J.3*** is a table showing again what was given in ***Section 6.1.2***, i.e. the 20-year traffic growth on the R44 corridor and the resulting spillover to an earlier time period once capacity is reached, but also how many vehicle trips are essentially removed from the network per scenario per year for the AM-peak hour. It can be seen that for all but three scenarios, the vehicle-trip subtractions reach a point where they are no longer subtracted from the AM-peak period, but only from the earlier time period, leaving the AM-peak hour to operate at capacity. As mentioned before, little was known about this earlier time period and the signal timing is very different.

It thus seemed to be more acceptable to not extrapolate at all than to extrapolate using formulas for which there would be much uncertainty about the accuracy of the outcome.

12.8 BENEFITS TO THE BICYCLE-SHARE USERS

The benefits to the users were calculated as described in ***Section 4.7.10***. For the bicycle-share users, it was assumed that their AM and PM benefits are the same.

For the parents, the total-travel costs for the null alternative fall away completely, as no more trips will be made in the modelled network. The total cost savings thus equal the total travel costs calculated for the null alternative and presented in ***Table 6.13***.

As stated in ***Section 4.7.10***, the mobility benefits to the SU users were also only evaluated up until the boundary of the study area. The VOCs for the cycling mode are zero (membership fee included in the cost analysis), so all VOCs from zone 2 (location of the Park-and-Ride) to the various destination zones turn straight into VOC savings. The travel distance, mean system speed and VOC for these trips are given in ***Table 12.18***. These are the same for the SU students and staff.

With the proposed cycling routes, all SU users will cycle from the Park-and-Ride past Paul Roos. This cycling distance equals 1.8 km. At an average cycling speed of 14 km/h, this distance takes 7.7 min to complete. Referring back to ***Section 6.2.2***, where the results for the null alternative were given, the travel time savings per road user are as shown in ***Table 12.19***, for the current SU routes. The costs related to these travel-time savings are given in ***Table 12.20***. As a recap, the routes were numbered as follows:

1. from zone 1 to zone 7 (R44 downstream)
2. from zone 1 to zone 9 (via Dorp St into Mill St)
3. from zone 1 to zone 12 (via Van Reede Rd to Suidwal Rd)
4. from zone 1 to zone 13 (via Van Reede Rd to Noordwal-Wes Rd)

Table 12.21 and ***12.22*** then give the total AM and overall travel-cost savings per SU road user and per route currently driven. The students can add to this amount their parking fee saving of ZAR 288.

Table 12.18: SU AM VOC and VOC savings per cycling user per year.

Year / Road user	VMT (km) for motorists from zone 2	AM mean system speed from zone 2 (km/h)	AM VOC / VOC saving (ZAR)
2020			
SU students and staff 1	1.33	12.92	2,057.91
SU students and staff 2	1.88	9.36	3,404.73
SU students and staff 3	1.73	8.22	3,357.28
SU students and staff 4	1.61	7.96	3,179.99
2021			
SU students and staff 1	1.33	11.28	2,193.72
SU students and staff 2	1.88	8.02	3,697.95
SU students and staff 3	1.73	7.21	3,612.50
SU students and staff 4	1.61	6.97	3,428.13
2022 to 2034			
SU students and staff 1	1.33	9.92	2,337.87
SU students and staff 2	1.88	6.94	4,013.06
SU students and staff 3	1.73	6.28	3,917.51
SU students and staff 4	1.61	6.06	3,725.30

Table 12.19: SU AM travel-time savings per cycling user per year.

Year / Road user	AM average travel time (min) for the null alternative	AM average travel-time saving (min)
2020		
Route 1	6.18	-1.53
Route 2	12.03	4.32
Route 3	12.60	4.89
Route 4	12.15	4.44
2021		
Route 1	7.08	-0.63
Route 2	14.05	6.34
Route 3	14.38	6.67
Route 4	13.88	6.17
2022 to 2034		
Route 1	8.04	0.33
Route 2	16.23	8.52
Route 3	16.50	8.79
Route 4	15.97	8.26

Table 12.20: SU AM travel-time cost savings per cycling user per year.

Year / Road user	Annual AM travel-time cost savings (ZAR)		
	SU students	SU staff	
2020		VOT 1	VOT 2
SU students and staff 1	-40.80	-306.00	-153.00
SU students and staff 2	115.20	864.00	432.00
SU students and staff 3	130.40	978.00	489.00
SU students and staff 4	118.40	888.00	444.00
2021			
SU students and staff 1	-16.80	-126.00	-63.00
SU students and staff 2	169.07	1268.00	634.00
SU students and staff 3	177.87	1334.00	667.00
SU students and staff 4	164.53	1234.00	617.00
2022 to 2034			
SU students and staff 1	8.80	66.00	33.00
SU students and staff 2	227.20	1704.00	852.00
SU students and staff 3	234.40	1758.00	879.00
SU students and staff 4	220.27	1652.00	826.00

Table 12.21: SU AM travel cost savings per cycling user per year.

Year / Road user	Annual AM travel cost savings (ZAR)		
	SU students	SU staff	
2020		VOT 1	VOT 2
SU students and staff 1	2,017	1,752	1,905
SU students and staff 2	3,520	4,269	3,837
SU students and staff 3	3,488	4,335	3,846
SU students and staff 4	3,298	4,068	3,624
2021			
SU students and staff 1	2,177	2,068	2,131
SU students and staff 2	3,867	4,966	4,332
SU students and staff 3	3,790	4,947	4,280
SU students and staff 4	3,593	4,662	4,045
2022 to 2034			
SU students and staff 1	2,347	2,404	2,371
SU students and staff 2	4,240	5,717	4,865
SU students and staff 3	4,152	5,676	4,797
SU students and staff 4	3,946	5,377	4,551

Table 12.22: SU overall travel cost savings per cycling user per year.

Year / Road user	Annual travel cost savings (ZAR)		
	SU students	SU staff	
2020		VOT 1	VOT 2
SU students and staff 1	4,034	3,504	3,810
SU students and staff 2	7,040	8,537	7,673
SU students and staff 3	6,975	8,671	7,693
SU students and staff 4	6,597	8,136	7,248
2021			
SU students and staff 1	4,354	4,135	4,261
SU students and staff 2	7,734	9,932	8,664
SU students and staff 3	7,581	9,893	8,559
SU students and staff 4	7,185	9,324	8,090
2022 to 2034			
SU students and staff 1	4,693	4,808	4,742
SU students and staff 2	8,481	11,434	9,730
SU students and staff 3	8,304	11,351	9,593
SU students and staff 4	7,891	10,755	9,103

For the comparison to literature, the travel time savings per km were determined for the cycling SU road users. For an average cycling speed of 14 km/h, it takes 4.29 min to cover a cycling distance of 1 km. The min / km values for the vehicle trips per SU route of travel are shown in ***Table 12.23***, and compared to those for the bicycle mode. In future, travel-time savings of over 50% can be achieved.

Table 12.23: Travel-time savings per km.

Year / Road user	AM average travel speed (km/h)	Min /km	Time saving per km (min)	%
2020				
SU students and staff 1	12.92	4.64	0.36	7.7
SU students and staff 2	9.36	6.41	2.12	33.1
SU students and staff 3	8.22	7.30	3.01	41.3
SU students and staff 4	7.96	7.54	3.25	43.1
2021				
SU students and staff 1	11.28	5.32	1.03	19.4
SU students and staff 2	8.02	7.48	3.20	42.7
SU students and staff 3	7.21	8.32	4.04	48.5
SU students and staff 4	6.97	8.61	4.32	50.2
2022 to 2034				
SU students and staff 1	9.92	6.05	1.76	29.1
SU students and staff 2	6.94	8.65	4.36	50.4
SU students and staff 3	6.28	9.55	5.27	55.1
SU students and staff 4	6.06	9.90	5.62	56.7

It must be remembered that these savings only relate to those felt in the study area, so the percentages could be higher if one studied the benefits for the entire commute.

13 BICYCLE-SHARING COST / BENEFIT ANALYSIS RESULTS

The objective of this research project was to perform a first-order economic viability assessment, meaning that the question essentially related more to whether bicycle-sharing is economically viable (or not) as a measure of congestion relief in Stellenbosch than determining the exact extent of this viability. The many scenarios and various VOT options led to a total of 580 results per economic evaluation technique, to be exact. It did not lie within the scope of this research to report back on each individual result. A general sense of the data is provided in this chapter, using simple maximum, minimum and average performance measures. Specific per-scenario results can be viewed in ***Appendix L***.

13.1 FIRST YEAR RATE OF RETURN

FYRRs could be determined without any problem, because all first-year benefits had been calculated. The results are given per scenario in ***Table L.1*** in ***Appendix L.1***. The benefits included the travel-cost benefits, health benefits and revenue all for the year 2020**.** The highest FYRR is 0.893, evaluated for scenario 11. The results for scenarios 5 and 17 are well-nigh the same, with FYRRs of 0.886 and 0.881, respectively. All these scenarios are phase 1 implementations: bicycle-sharing only for scholars, with a value of time taken to be 0.5 that of the wage rate, and assuming a vehicle occupancy of 1.5 persons. The lowest FYRRs (values between 0.16 and 0.17) were observed for scenarios 40, 46, 52, 94, 100 and 106, which entail a bicycle-sharing scheme for all three road-user groups. This is not to say, though, that scenarios are economically less viable, because their potential for revenue is much higher than that for the smaller schemes. The average FYRR is 0.373.

13.2 NET PRESENT VALUE

Although only the first-year travel cost savings could be computed, a NPV was still calculated using this value and the present-worth total health benefits and revenue. The results are revealed in ***Table L.2*** in ***Appendix L.2***. For the scenarios involving a high uptake in cycling, positive NPVs already exist. Looking at all the scenarios, the values range from -R39,054,032 to R36,239,179. This high positive value gives an indication of how great the economic viability may essentially be. The average value is -R4,882,751. The average first-year revenue was calculated to be R1,849,322, which means it will take, on average, less than 3 years (out of the total 15 years) to recover the difference.

Just to get a feel for the numbers, the NPV calculation was redone, but this time multiplying the travel-cost benefits by 7.5 years, i.e. half of the service life. The results are shown in ***Table L.3*** in ***Appendix L.2***. All values are well above the breakeven point. The highest value approaches R0.245 billion, and the lowest is nearly R25,44 million. The average is a few Rand short of R86.0 million. This undeniably signifies economic viability.

13.3 BENEFIT / COST RATIO

The BCR per scenario was computed using the same values as for the NPV analysis. The results are presented in ***Table L.4*** in ***Appendix L.3***. The highest result is 1.75 and the lowest is 0.48. The average is 0.9. These results then too denote economic viability when referring back to ***Section 4.9.2*** where it was stated that the economic viability of a project or alternative is seen as medium when the BCR lies between 1.5 and 2, and high when it is above 2.

A factor of 7.5 was also applied to the travel-cost benefits in the BCR analysis. All results are above 1, with the highest being 7.19 and the average being 3.08. As a comparison, a BCR of 1.82 was evaluated for *Capital Bikeshare* in Washington, D.C. (Bicycle-sharing blog, 2013) also for a discount rate of 3%.

13.4 COST / BENEFIT ANALYSIS FOR THE BICYCLE-SHARE USERS

The NPV and BCR per potential bicycle-share user per year are given in ***Tables 13.1*** and ***13.2*** for the school parents and ***Tables 13.3*** and***13.4*** *for the SU users*. The values show that the membership of fees of R2,500 and R3,000 (the cost), respectively, still allow the users to reap fair annual benefits.

Table 13.1: NPV for the parents of potential school-learner bicycle-share users.

Road user	2020	2021	2022 to 2034
non-working school parents	5,510	6,241	7,069
	VOT 1 (ZAR); factor = 0.5		
working school parents	20,008	23,242	26,949
	VOT 2 (ZAR); factor = 02.5		
working school parents	12,440	14,368	16,572

Table 13.2: BCR for the parents of potential school-learner bicycle-share users.

Road user	2020	2021	2022 to 2034
non-working school parents	2.84	3.08	3.36
	VOT 1 (ZAR); factor = 0.5		
working school parents	7.67	8.75	9.98
	VOT 2 (ZAR); factor = 02.5		
working school parents	5.15	5.79	6.52

Table 13.3: NPV for the potential SU bicycle-share users.

Year / Road user	NPV (ZAR)		
	SU students	SU staff	
		VOT 1	VOT 2
2020			
SU students and staff 1	1,034	504	810
SU students and staff 2	4,040	5,537	4,673
SU students and staff 3	3,975	5,671	4,693
SU students and staff 4	3,597	5,136	4,248
2021			
SU students and staff 1	1,354	1,135	1,261
SU students and staff 2	4,734	6,932	5,664
SU students and staff 3	4,581	6,893	5,559
SU students and staff 4	4,185	6,324	5,090
2022 to 2034			
SU students and staff 1	1,693	1,808	1,742
SU students and staff 2	5,481	8,434	6,730
SU students and staff 3	5,304	8,351	6,593
SU students and staff 4	4,891	7,755	6,103

Table 13.4: BCR for the potential SU bicycle-share users.

Year / Road user	BCR		
	SU students	SU staff	
		VOT 1	VOT 2
2020			
SU students and staff 1	1.34	1.17	1.27
SU students and staff 2	2.35	2.85	2.56
SU students and staff 3	2.33	2.89	2.56
SU students and staff 4	2.20	2.71	2.42
2021			
SU students and staff 1	1.45	1.38	1.42
SU students and staff 2	2.58	3.31	2.89
SU students and staff 3	2.53	3.30	2.85
SU students and staff 4	2.40	3.11	2.70
2022 to 2034			
SU students and staff 1	1.56	1.60	1.58
SU students and staff 2	2.83	3.81	3.24
SU students and staff 3	2.77	3.78	3.20
SU students and staff 4	2.63	3.59	3.03

14 GEOMETRIC IMPROVEMENT BENEFIT ANALYSIS

For the geometric-improvement alternative, an additional right-turn and left-turn lane were added to the southern and eastern approach of the R44 / Van Reede intersection, respectively.

The total cost of the project was given in ***Section 4.5.3*** to be R4.57 million.

All the input parameters to the benefit analysis for this alternative were calculated as for the null and bicycle-sharing alternative. Since the results are single values, they are not presented in subsections, as was done for the other alternatives.

A summary of the AM mobility parameters (VMT, VHT and mean system speed) and travel costs for the geometric-improvement alternative is given in ***Table 14.1***. The travel-cost savings are listed in ***Table 14.2***. Since this alternative comprised only a geometric capacity improvement, not a reduction in vehicle trips, the O-D and VMT matrices for this alternative were the identical to those for the null alternative. The new VHT matrix and all the benefit-analysis details are provided on the attached CD.

Table 14.1: A summary of the AM mobility parameters and travel costs for the 2020 geometric-improvement alternative.

VMT (km)	15,349
VHT (h)	1,448
Mean system speed (km/h)	10.60
VOC (ZAR)	26,095,639
Travel-time cost VOT 1 (ZAR)	26,057,878
Travel-time cost VOT 2 (ZAR)	13,028,939
Travel-time cost VOT 3 (ZAR)	20,846,303
Travel-time cost VOT 4 (ZAR)	10,423,151
CO_2 emission cost (ZAR)	1,026.20
Total travel cost with VOT 1 (ZAR)	52,154,543
Total travel cost with VOT 2 (ZAR)	39,125,604
Total travel cost with VOT 3 (ZAR)	46,942,968
Total travel cost with VOT 4 (ZAR)	36,519,816

Table 14.2: Travel-cost savings for the 2020 geometric-improvement alternative.

	AM	All hours
VOC (ZAR)	658,984	
Travel-time cost saving VOT 1 (ZAR)	1,333,697	
Travel-time cost saving VOT 2 (ZAR)	666,849	
Travel-time cost saving VOT 3 (ZAR)	1,066,957	
Travel-time cost saving VOT 4 (ZAR)	533,479	
CO_2 emission cost saving (ZAR)	36	
Total travel cost saving with VOT 1 (ZAR)	1,992,717	3,985,434
Total travel cost saving with VOT 2 (ZAR)	1,325,868	2,651,736
Total travel cost saving with VOT 3 (ZAR)	1,725,977	3,451,954
Total travel cost saving with VOT 4 (ZAR)	1,192,499	2,384,998

The total travel-cost savings for the geometric-improvement alternative range between R2.38 million and R3.99 million. The total travel-cost savings for all hours of the year were taken to be a factor of 2 higher than the annual AM-peak travel-cost savings, as decsribed in ***Section 4.5.3***.

A summary of the control delay, level of service and back of queue for the R44 / Van Reede intersection and the geomteric improvement alternative for the AM-peak period is given in ***Appendix K, Table K.1***. The same summary for the 2020 null alternative is given in ***Table K.2***, as a comparison. The reduced delay for the southern-approach right-turn and eastern-approach left-turn is 4.09 min and 1.72 min per motor vehicle, respectively.

The results of the CBA for this alternative are given along with the bicycle-sharing results in ***Appendix L***, at the bottom of the tables. The ranges of the results are as follows for the three economic evaluation techniques:

- FYRR and BCR (amended formula): 0.39 to 0.65
- NPV: -R1.58 million to -R2.78 million
- BCR (with benefits multiplied by 7.5): 2.44 to 4.91
- NPV (with benefits multiplied by 7.5): R8.85 million to R17.85 million

These results are compared to those for the bicycle-sharing alternative in ***Chapter 15***.

15 CONCLUSION AND RECOMMENDATIONS

15.1 DISCUSSION AND SUMMARY OF FINDINGS

In this section, only the results that were of importance to evaluating the economic viability of the proposed bicycle-sharing scheme for Stellenbosch are discussed.

The first results were presented for the base model, i.e. the year 2015, and the null alternatives. The mean system speed for the AM-peak prevailing conditions, i.e. 2015, was calculated to be 18.13 km/h. For the null alternatives, the AM-peak mean system speeds are 10.09 km/h, 8.69 km/h and 7.51 km/h for the years 2020, 2021 and all years after that, respectively. When bearing in mind that the average cycling speed is 14 km/h (a conservative value), this cycling speed is almost double the AM-peak mean system speed at capacity. The null-alternative parameters were evaluated by applying the traffic growth rate factor (defined to be 3%). The peak-spreading trend was also quantified, and it was found that for the studied R44 corridor just over 1,000 vehicles will have spilled over to what is assumed to be an earlier time period by the end of 2034. The total travel costs for the 2020 null alternative range from R37.7 million to R54.1 million. A range of values results because of the VOT variables that were tested as part of a sensitivity analysis.

In Chapter 8, the total number of potential bicycle-share users and vehicle-trip savings were identified for each of the three road-user groups. 358 scholars, 490 SU students and 241 SU staff members were identified as potential users, with associated vehicle-trip savings of 266, 425 and 221, respectively.

Various modifications of the conceptual design proposed in Chapter 9 were analysed in combination with each other to evaluate the benefits, and hence economic viability, mainly for varying scheme sizes and levels of cycling uptake. This resulted in a wide range of outputs for each parameter, which made a comprehensive presentation of the results here a challenging task. As mentioned before though, it was only first-order values that were sought after.

The total service-life costs for a phase 1 implementation (bicycle-sharing for scholars only) vary from R17.0 million (208 bicycles) to R26.3 million (415 bicycles). For bicycle-sharing made available to both scholars and SU students, the costs range from R39.9 million (492 bicycles) to R66.6 million (983 bicycles). A scheme that is to be implemented for all three user groups was estimated to cost between R45.3 million (631 bicycles) and R81.8 million (1262 bicycles)

The potential service-life revenues range from R6.8 million (a phase 1 implementation) to as much as R61.2 million (bicycle-sharing for all potential users) - as a result of the casual riders that come with an SU bicycle-sharing implementation.

For the bicycle-sharing alternative, the 2020 AM-peak mean system speeds for various scenarios were found to vary from 11.37 km/h to 16.01 km/h. The range of the resulting total 2020 AM-peak travel-cost savings was computed to be R3.9 million to R14.0 million, accounting for the various VOTs and vehicle occupancies. The order of magnitude for the CO_2-emission savings (and costs) was less than 1,000 and thus deemed insignificant when assessed against all the other travel savings. Total annual health benefits for various scenarios were evaluated to be between R33,000 and R103,000. Put altogether, the total savings for 2020 were worked out to lie between R5.8 million and R21,0 million.

An average FYRR of 0.37, an average NPV of -R4,882,751 and an average BCR of 0.9 were evaluated for the bicycle-sharing alternative. It must be noted that whilst the NPV and BCR values do include service-life revenues and health benefits, only the travel-cost benefits for 2020 formed part of the appraisal, and it is consequently expected that the real NPV and BCR are considerably higher. A ballpark figure for NPV and BCR was determined assuming that the total travel-cost savings for the service life of the system equal 7.5 times those appraised for 2020. The average NPV and BCR then became R86.0 million and 3.08, respectively. This is not believed to be an overestimation of the expansion factor, on the contrary in point of fact. These values are hence indicative of a pronounced economic potential for the proposed bicycle-sharing scheme for commuter traffic in Stellenbosch. Even though the cost savings for the scenarios with lower approximations of VOT are less extreme, they do not steer away from the fact that the scheme was found to be economically viable.

For the bicycle users themselves, the influence of the varying VOT between the users on total travel-cost savings is more momentous. The savings also relate closely to the route that is currently taken through the network. BCRs ranging from 1.17 to 9.98 were found.

The geometric improvement to the R44 / Van Reede intersection was evaluated in terms of its costs and benefits as a comparison. The AM-peak mean system speed of 10.6 is only marginally higher than that measured for the null alternative, and the 2020 total travel-cost savings, varying between R1.2 million and R2.0 million, are significantly lower than for the average bicycle-sharing scenario. It must be remembered that many of the bicycle-sharing scenarios have economic-benefit values very high above average, in fact. The BCR (=FYRR) and NPV ranges for the geometric-improvement alternative are 0.39 to 0.65 and -R1.58 million to -R2.78 million, respectively. Applying the same expansion factor of 7.5 as described above, these values become 2.44 to 4.91 and R8.85 million to R17.85 million. It is especially for this NPV value that the bicycle-sharing alternative is the front-runner, because the bicycle-sharing alternative accumulates revenue over the service life, and the geometric-improvement alternative does not.

When inspecting the general results of the economic evaluation more closely, the base case B9 (all components included) of the operational model, in comparison to modification M15 (exclude 'luxuries'), does not in any way lay on the line the viability of a scenario. For this reason, it is recommended that the scheme be implemented with the 'luxury'.

It is also recommended that bicycle-sharing should be made available for SU students soon after the deployment for scholars (if not at the same time). For three such scenarios, namely S75, S93 and S129, the average (economically viable) results are presented in ***Table 15.1***. These are considered to exemplify a realistic potential uptake of cycling. The modifications of the scenarios are as follows:

- S75 – scheme size: bicycles for 75% of potential users; ridership: 75% of potential users designed for cycle; fare structure: as calculated; operational model: all components included.
- S93 – scheme size: bicycles for 75% of potential users; ridership: 50% of potential users designed for cycle; fare structure: as calculated; operational model: all components included.
- S129 – scheme size: bicycles for 50% of potential users; ridership: 50% of potential users designed for cycle; fare structure: as calculated; operational model: all components included.

As has been made known, the extrapolation of travel benefits related to traffic volumes is a complex procedure, which thus means that no simple report can be given on the extent to which the appraised benefits for the case study can be reaped in other parts of Stellenbosch. The evaluated benefits are quite extensive, and it is believed that bicycle-sharing can bring about congestion relief in Stellenbosch way beyond the limits of the case study. Many scholars were surveyed to travel along the M12 / R310

Table 15.1: CBA results for scenarios S75, S93 and S129.

	S75	S93	S129
FYRR	0.24 to 0.36	0.18 to 0.27	0.22 to 0.34
BCR_1	0.73 to 0.85	0.51 to 0.60	0.63 to 0.75
NPV_1	-R8.3 million to -R14.9 million	-R27.4 million to -R22.3 million	-R16.3 million to -R11.19 million
$BCR_{7.5}$	2.05 to 2.94	1.5 to 2.9	1.88 to 2.74
$NPV_{7.5}$	R58.6 million to R108.0 million	R28.1 million to R66.2 million	R39.2 million to R77.4 million

arterial from the south-west on a daily basis, so perhaps this is the next arterial to consider for an implementation of bicycle-sharing. All arterials meet in the middle – the town, so if bicycles can reduce vehicle trips made from all sides, the congestion relief in the centre will be immense.

15.2 DISCUSSION OF PROBLEMS

Reality did not take the form that was initially anticipated, and the scale of the research project grew unexpectedly at each step along the way. The most significant problem stumbled upon during the research process related to traffic growth and its link to V-D functions. It was not foreseen that the traffic growth would primarily be found to occur outside of the peak hour, and that the non-linear relationship that exists between volume and delay would prove extrapolation of the benefits to be such an intricate task.

15.3 CONCLUSION

The Stellenbosch transportation network is saturated with private light-motor vehicles. Amongst the middle and upper class, mass motorisation is most discernible and gridlock consequently manifests itself in the peak hours. The primary objective of this research project was to evaluate the economic viability of a theoretical bicycle-sharing scheme for school and university destined commuter traffic in the town of Stellenbosch as a measure of congestion relief. The secondary objectives were:

1. to determine the first-order benefit and cost estimates of the proposed bicycle-sharing scheme (case study only) and present them in the form of a NPV, BCR, and FYRR.
2. to conceptually design a premier bicycle-sharing scheme for the school and university destined commuters of Stellenbosch so as to attain the highest possible NPV, BCR and FYRR.

On the whole, it can be confidently stated that bicycle-sharing for Stellenbosch is an economically viable affair, meaning that the research statement was true. The former of the secondary objectives was partially met. FYRRs ranging between 0.23 and 0.88 were determined for the scheme that was believed to have a total service life of 15 years. A detailed conceptual design of a bicycle-sharing scheme for Stellenbosch was carried out, but whether it is 'premier' cannot be adjudged by the author. In summary:

- will the proposed bicycle-sharing scheme reduce traffic congestion in the study area? Yes.
- to which extent will it do so? It depends (mainly on the size of the scheme and the ridership).

Championing the scheme and developing an all-encompassing bicycle-sharing strategy is key to the success of this congestion-relief solution. Furthermore, it is essential that the schools, SU, politicians, municipality and the business sector join forces in order for the project to be launched without regret. It is also to be the responsibility of the authorities to continuously improve the cycle network and infrastructure to signify to all road users and residents the valid place and permanence that cycling is to have in Stellenbosch.

Whilst the geometric improvement at the R44 / Van Reede intersection was found to be economically viable, many of the bicycle-sharing scenarios were learnt to be more so. Looking into the future and the growth (economic and traffic) that will come about, the roadway-capacity-expansion solution is believed not to be sustainable. Benefits will be reaped for a few years, but the network congestion will then eventually be back at square one, except that due to space constraints, no further expansion will be probable. The growth will then likely send the municipality into a state of panic when growth should, in fact, be welcomed for all the benefits it can bestow. Roadway capacity expansion also does not reduce the number of vehicles entering the CBD or reduce the town's unmanageable high parking demand. It is, furthermore, only on some of the arterials where expansion is even still imaginable; in town, there is no vacant land to do so. Besides, the question is moreover: does it even make sense to increase capacity that is only required for the peak periods? In the text, the question was posed whether Stellenbosch can 'build' its way out of congestion. The answer is: no, it cannot.

The notion behind the bicycle-sharing scheme for Stellenbosch is a concept of: liveability on the inside, motorisation on the outside. This relates to transforming Stellenbosch into a people-friendly, not a car-friendly town, i.e. it is the bicycle that is to be king, not the private motor vehicle. All of this goes along with the vision described in the 2015 Cycling Plan for the Town of Stellenbosch: "*By 2030, cycling within and around Stellenbosch has become the popular form of mobility that is safe, convenient, and is accepted and promoted by all"*.

Except for the safety and security concerns, in the grand scheme of things and in comparison to even only the financial benefits that can be achieved, the barriers to cycling seem to be an easy fix. A long travelling distance and too much and / or heavy baggage were addressed in the conceptual design already, and building amenities, such as showers, at the workplace could be next. One can even look into mechanisms that make for easier pedalling.

Finally, mobility is a necessity, but congestion could become a choice. If change is desired, then this wish (or rather need) needs to be committed to, even if it requires a change in mindset. In conclusion: is bicycle-sharing an adjustment to present-day habits? Yes. Is it a step backward? Absolutely not. Bicycle-sharing is not only a matter of reinventing the wheel, but reinventing the city.

15.4 SUMMARY OF CONTRIBUTIONS

Table 15.2 is a summary of what this research project has achieved, and what contributions it is believed to have made or still make to society.

Table 15.2: Summary of the contributions of the research project.

Contribution	YES	NO
Chapter 1		
1. Quantified the traffic congestion on Stellenbosch's major arterials and main interior routes over a five-year span. • Findings are not specific to bicycle-sharing; they can serve as an input to many other traffic studies undertaken for Stellenbosch.	X	
Chapter 2		
2. Performed an exhaustive literature review on bicycle-sharing.	X	
Chapter 4		
3. Calculated a VOT for AM commuter traffic in Stellenbosch. • Very high average annual incomes found for the school parents (which is a reflection on some typical income rates for Stellenbosch), so all mean SA VOT values applied in travel-time-cost evaluations greatly underestimate the costs. • Not known to have been done before and thus can be used for other Stellenbosch travel-cost analyses.	X	
Chapter 5		
4. Conducted a 2015 traffic-count study at every intersection in the study area. • Due to lack of resources this is typically not done. • These traffic counts were very valuable though, because they served as the input to a traffic demand model (see next point).	X	
5. Developed an AM-peak-hour calibrated traffic demand model in Visum for the study area, which included validating V-D functions suitable for Stellenbosch (calibration done using probe data). • The study area is a major congestion hotspot in Stellenbosch, so the model is not only of significance to this research project.	X	
6. Using the model, quantified the prevailing traffic conditions in the study area. • The delay was calculated at every intersection in the study area. The ICA reports are formulated Excel spreadsheets with which all kinds of scenarios (not limited to bicycle-sharing) can be tested in terms of delay and back of queue. • CO_2 emissions were also assessed.	X	
Chapter 6		
7. Using the model, quantified the AM-peak-hour traffic conditions and travel costs for the years 2020 to 2035. • Also has a significance beyond this research project.	X	
Chapter 7		
8. Initiated and was part of a study that analysed school-related travel and its contribution to the overall congestion in Krigeville. • Again, not only of importance to this research project, as all kinds of data were collected (more than what is shared in this research project). 9. Although with the intention to get out travel data for the potential-user calculation, a survey was conducted for the SU students and staff that collected data valuable beyond this research project. • To the knowledge of the author, a survey with such response rates has not been performed before. • Only for one arterial, but it is one of the main ones. • The same survey can now easily be distributed to the wider SU community.	X	

10. Identified the current barriers to cycling from the surveys (what the participants say, not a mere assumption of what the barriers could be).	X	
Chapter 8		
11. Identified the potential commuter cyclists. • These could also be potential users of another alternative mode of transport.	X	
Chapter 9 to 13		
12. Did a full conceptual design of a bicycle-sharing scheme that is believed to be suited to Stellenbosch. This design is not limited to the study area and was especially designed with the bigger picture in mind.	X	
• Took the first step in developing a brand	X	
13. Determined the costs over the service life of the scheme (15 years) based on the conceptual design:	X	
○ Construction costs	X	
▪ included parking-lot costs	X	
▪ included *en route* bicycle-facility costs (done in-depth in Cycling Plan)		X
○ Real-estate / right-of-way costs		X
○ Equipment costs	X	
○ Launch and installation costs	X	
▪ included marking costs		X
○ Operating and maintenance costs	X	
14. Determined the revenue of the scheme over the service life based on the conceptual design.	X	
15. Determined the benefits of the scheme over the service life based on the conceptual design.		X
• Determined the benefits of the scheme for year one.	X	
16. Determined:		
NPV		X
BCR		X
IRR		X
FYRR	X	
Chapter 14		
17. Compared an in-progress roadway capacity expansion alternative (the standard measure of congestion relief in Stellenbosch) to the bicycle sharing alternative.	X	
General		
18. May have found the solution to the traffic congestion problem in Stellenbosch. A solution that is economically viable, smart and sustainable.	X	

15.5 RECOMMENDATIONS FOR FURTHER RESEARCH

The recommendations for further research are dependent on how this research is received as a measure of congestion relief. If the proposed solution of a bicycle-sharing scheme for school and university destined commuter traffic in Stellenbosch is identified by the authorities to be potentially commendable and is to form part of the political agenda for further consideration, then the following recommendations for additional research (but specific to the proposed solution) are made:

1. The analysis procedures defined in this research project should be looked into and repeated for what was said to be phase 3 of the deployment: bicycle-sharing also for general commuters. A key component of this further research is firstly verifying that the remaining road users are primarily commuters, and then determining the travel patterns of these general commuters. For example, what are the every-day destinations of these commuters? I.e. where should the additional docking stations be sited and how many docks should be provided?
    a. When this is carried out, it is recommended to improve on the analysis procedures applied in this research project. The AM model, should be exactly that: an AM model, not an AM-peak model, so that the effects of peak spreading can be understood better and accounted for. The state of maximum network capacity should also be examined more closely for each of the network entry points. Likewise, a better perception of the PM traffic conditions should be strived for. The PM peak is more spread out than the AM peak. So, when is it that most of the potential users will cycle back to the Drop-and-Go and Park-and-Ride? And, how many vehicle trips should be removed from the network for each time period?
2. Once the CBA has been performed for all three phases of implementation, the findings should be compared to the results of the same economic evaluation techniques applied to a theoretical, but potential bus rapid transit (BRT) system for Stellenbosch – the closest alternative congestion-relief measure to bicycle-sharing.
3. If the bicycle-sharing solution then comes out on top, the CBA for bicycle-sharing should be extended to the whole of Stellenbosch. Due to the nature of the many influencing factors, this extended CBA should not simply be an approximate extrapolation, but a new analysis should be undertaken for the arterials for which bicycle-sharing is deemed to be feasible. For this, it is strongly advised that the traditional four-step model is applied, since the service area of the system will then be much greater in size. A more detailed look into accident reductions, and the related cost savings, is then also recommended.
4. In coexistence with bicycle-sharing, congestion pricing reforms and their practicality could be explored, because an alternative mode of transport will then be accessible to the road users.
5. Lastly, a future research project may want to investigate the possibility, and again feasibility, of a train connection between the Somerset West area and Stellenbosch. Comments in this regard were made by various study participants independently of each other.

GLOSSARY

Active transportation
The mode of transport referring either to walking or cycling.

Analysis period
A single time period during which a capacity analysis is performed on a either a network node or link.

Approach
A set of lanes at an intersection that accommodate all turn movements from a given direction.

Arterial
A signalised street that serves primarily through traffic and provides access to adjoining properties as a secondary function.

Back of queue
The maximum backward extent of queued vehicles at an intersection, measured from the stop line to the last queued vehicle.
The unit is veh.

Bicycle facility
A road, path, or way specifically designated for bicycle travel, whether exclusively or with other vehicles or pedestrians.

Bicycle lane
A portion of a roadway designated by striping, signing, and pavement markings for the preferential or exclusive use of bicycles.

Bicycles path
A bikeway physically separated from motorised traffic by an open space or barrier, either within the highway right-of-way or within an independent right-of-way.

Bicycle track
A one-way bicycle facility separated from both motor vehicle traffic and the sidewalk by low curbs.

Bicycle-sharing scheme
A non-motorised transportation service for short distance point-to-point trips in which bicycles are made available to users on a 'sharing' basis.

Bill of Quantities
A detailed statement of work done, associated costs and other details for a construction by contract.

Capacity
The maximum sustainable hourly flow rate at which vehicles can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, environmental, traffic and control conditions.

Commuter
A person travelling between their place of residence and work or educational facility.

Conflict
The crossing, merging, or diverging of two traffic movements at an intersection.

Congestion
A traffic condition that arises when demand approaches or exceeds network's capacity. It is characterised by a low level of service.

Congestion pricing
The practice of charging tolls for use of all or part of a roadway facility or network according to the severity of congestion.

Cycle
A complete sequence of signal indications.

Cycle length
The time elapsed between the endings of two sequential terminations of a given interval.

Delay
Additional travel time experienced by a road user beyond that required to travel at the desired speed.

Demand
The number of vehicles or other roadway users desiring to use a given network during a specific time period.

Demand flow rate
The count of vehicles arriving at the system element during the analysis period, converted to an hourly rate.

Discount rate
A percentage figure representing the opportunity cost of capital for an investment, used for converting periodic costs and benefits for a project to present value or to equivalent annual cost.

Drop-and-Go zone
A zone where drivers park temporarily to offload passengers. A vehicle is never left unattended.

Flow rate
The equivalent hourly rate at which vehicles or other roadway users pass over a given point or section of a lane or roadway during a given time interval.

Free flow
A flow of traffic unaffected by upstream or downstream conditions.

Global Navigation Satellite System
A satellite system that is used to pinpoint the geographic location of a user's receiver anywhere in the world.

Green time
The duration of the green indication for a given movement at a signalised intersection.

Last mile
The short distance (often too far to walk) between a commuter's home and public transit and / or transit stations to the workplace.

Level of Service
A quantitative stratification of a performance measure or measures that represent quality of service, measured on a scale from A to F scale, with A representing the best operating conditions from the traveller's perspective and LOS F the worst.

Major street
The street not controlled by STOP signs at a two-way STOP-controlled intersection.

Minor street
The street controlled by STOP signs at a two-way STOP-controlled intersection.

Movement groups
An organisation of traffic movements at a signalised intersection to facilitate data entry. A separate movement group is established for (1) each turn movement with one or more exclusive turn lanes and (2) the through movement (inclusive of any turn movements that share a lane).

Occupancy rate
The number of occupants of a vehicle, expressed in persons per vehicle.

Park-and-Ride
A system for reducing urban traffic congestion, in which road users leave their car in a parking lot on the outskirts of a town / city and travel to the city centre using public transport, e.g. public bicycles.

Peak hour
The hour of the day in which the maximum traffic volume occurs.

Permitted turn
A left or right turn at a signalised intersection that is made by a vehicle during a time in the cycle in which the vehicle does not have a right-of-way.

Phase
The part of the signal cycle allocated to any combination of traffic movements receiving the right-of-way simultaneously during one or more intervals.

Present worth
The present amount that is equivalent to specified amounts of money in different time periods, at a given discount rate.

Pretimed control
A signal control in which the cycle length, phase plan, and phase times are preset to repeat continuously.

Protected turn
The left or right turns at a signalised intersection that are made by a vehicle during a time in the cycle when the vehicle has the right-of-way.

Queue
A line of vehicles, bicycles, or persons waiting to be served due to traffic control, bottlenecks, or other causes.

Queue length
The distance between the upstream and downstream end of the queue.

Residual or Salvage value
The value of an investment or capital outlay remaining at the end of the study period.

Saturation flow rate
The equivalent hourly rate at which previously queued vehicles can traverse an intersection approach under prevailing conditions, assuming that the green signal is available at all times and no lost times are experienced.

Semi-actuated control
A signal control in which some approaches (typically on the minor street) have detectors to call a phase at a signalised intersection, and other approaches (typically on the major street) do not.

Service life
Maximal recorded life of a product or product before it needs replacing.

Traffic calming
Measures used to control the speed and movement of vehicle within a particular area.

Travel time delay
The difference between actual travel time and travel time during free-flow or off-peak conditions.

Utility cycling
Cycling done as a means of transport rather than as a sport or leisure activity.

Value of Time
The opportunity value attributed to one hour of a user's time.

Volume-to-capacity ratio
The ratio of flow rate to capacity for a system element.

Volume-delay function
A mathematical equation that expresses the relationship among traffic volumes, capacity, and the time required to travel one kilometre.

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The economic evaluation of a bicycle-sharing scheme for school and university destined commuter traffic in Stellenbosch, South Africa that is proposed as a sustainable mode of transport to relieve traffic congestion:

A case study for the R44 inbound traffic from Somerset West

APPENDICES

by
Dominique Andrea ter Huurne

Thesis presented in fulfilment of the requirements for the degree of Master of Science in the Faculty of Engineering at Stellenbosch University

Supervisor: Dr Johann Andersen
Department of Civil Engineering

March 2016

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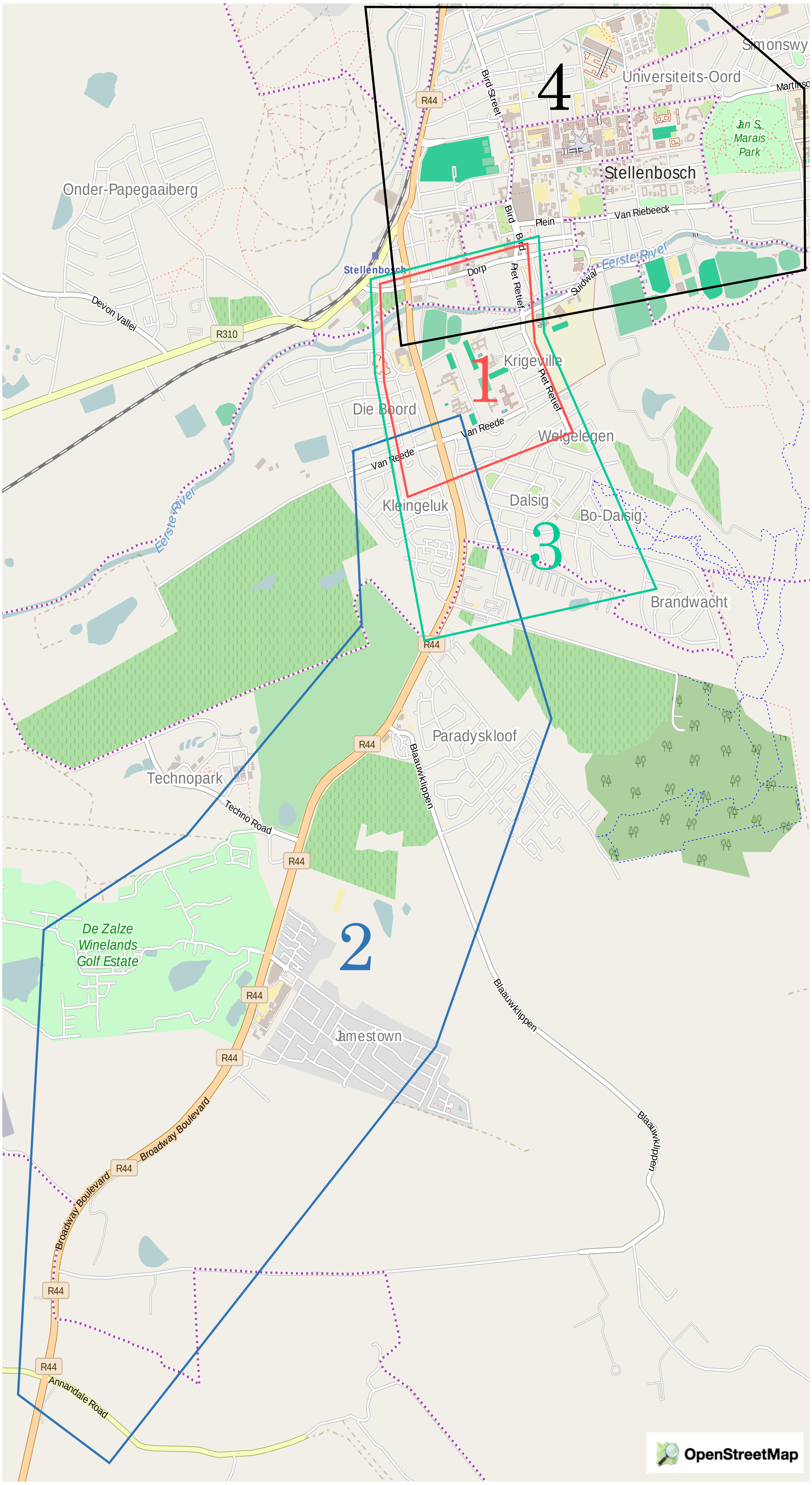


Figure A.1: Map of Stellenbosch showing the location of the more zoomed-in maps presented in the various chapters.

A.2 SCENARIO MANAGEMENT FOR THE BICYCLE-SHARING ALTERNATIVE

Table A.1: Description of the modifications for the bicycle-sharing alternative.

Base Case / Modification	Scheme size	Ridership	Fare structure	Operational model
B1	-	-	-	-
B2	school learners - bicycles for all potential users	-	-	-
B3	SU students - bicycles for all potential users	-	-	-
B4	SU staff - bicycles for all potential users	-	-	-
B5	-	school learners – all potential users cycle	-	-
B6	-	SU students - all of potential users cycle	-	-
B7	-	SU staff - all of potential users cycle	-	-
B8	-	-	as calculated	-
B9	-	-	-	all components included
M1	school learners - bicycles for 75% of potential users	-	-	-
M2	SU students - bicycles for 75% potential users	-	-	-
M3	SU staff - bicycles for 75% potential users	-	-	-
M4	school learners - bicycles for 50% of potential users	-	-	-
M5	SU students - bicycles for 50% potential users	-	-	-
M6	SU staff - bicycles for 50% potential users	-	-	-
M7		school learners - 75% of potential users cycle	-	-
M8		SU students - 75% of potential users cycle	-	-
M9		SU staff - 75% of potential users cycle	-	-
M10	-	school learners - 50% of potential users cycle	-	-
M11	-	SU students - 50% of potential users cycle	-	-
M12	-	SU staff - 50% of potential users cycle	-	-
M13	-	-	10% increase to B8	-
M14	-	-	10% decrease to B8	-
M15	-	-	-	exclude 'luxuries'

Table A.2: The scenarios for the bicycle-sharing alternative.

Scenario	Scheme size	Ridership	Fare structure	Operational model
S1 = null alternative				
S2	B2	B5	B8	B9
S3	B2, B3	B5, B6	B8	B9
S4	B2, B3, B4	B5, B6, B7	B8	B9
S5	B2	B5	B8	M15
S6	B2, B3	B5, B6	B8	M15
S7	B2, B3, B4	B5, B6, B7	B8	M15
S8	B2	B5	M13	B9
S9	B2, B3	B5, B6	M13	B9
S10	B2, B3, B4	B5, B6, B7	M13	B9
S11	B2	B5	M13	M15
S12	B2, B3	B5, B6	M13	M15
S13	B2, B3, B4	B5, B6, B7	M13	M15
S14	B2	B5	M14	B9
S15	B2, B3	B5, B6	M14	B9
S16	B2, B3, B4	B5, B6, B7	M14	B9
S17	B2	B5	M14	M15
S18	B2, B3	B5, B6	M14	M15
S19	B2, B3, B4	B5, B6, B7	M14	M15
S20	B2	M7	B8	B9
S21	B2, B3	M7, M8	B8	B9
S22	B2, B3, B4	M7, M8, M9	B8	B9
S23	B2	M7	B8	M15
S24	B2, B3	M7, M8	B8	M15
S25	B2, B3, B4	M7, M8, M9	B8	M15
S26	B2	M7	M13	B9
S27	B2, B3	M7, M8	M13	B9
S28	B2, B3, B4	M7, M8, M9	M13	B9
S29	B2	M7	M13	M15
S30	B2, B3	M7, M8	M13	M15
S31	B2, B3, B4	M7, M8, M9	M13	M15
S32	B2	M7	M14	B9
S33	B2, B3	M7, M8	M14	B9
S34	B2, B3, B4	M7, M8, M9	M14	B9
S35	B2	M7	M14	M15
S36	B2, B3	M7, M8	M14	M15
S37	B2, B3, B4	M7, M8, M9	M14	M15
S38	B2	M10	B8	B9
S39	B2, B3	M10, M11	B8	B9
S40	B2, B3, B4	M10, M11, M12	B8	B9
S41	B2	M10	B8	M15
S42	B2, B3	M10, M11	B8	M15
S43	B2, B3, B4	M10, M11, M12	B8	M15
S44	B2	M10	M13	B9

S45	B2, B3	M10, M11	M13	B9
S46	B2, B3, B4	M10, M11, M12	M13	B9
S47	B2	M10	M13	M15
S48	B2, B3	M10, M11	M13	M15
S49	B2, B3, B4	M10, M11, M12	M13	M15
S50	B2	M10	M14	B9
S51	B2, B3	M10, M11	M14	B9
S52	B2, B3, B4	M10, M11, M12	M14	B9
S53	B2	M10	M14	M15
S54	B2, B3	M10, M11	M14	M15
S55	B2, B3, B4	M10, M11, M12	M14	M15
S56	M1	B5	B8	B9
S57	M1, M2	B5, B6	B8	B9
S58	M1, M2, M3	B5, B6, B7	B8	B9
S59	M1	B5	B8	M15
S60	M1, M2	B5, B6	B8	M15
S61	M1, M2, M3	B5, B6, B7	B8	M15
S62	M1	B5	M13	B9
S63	M1, M2	B5, B6	M13	B9
S64	M1, M2, M3	B5, B6, B7	M13	B9
S65	M1	B5	M13	M15
S66	M1, M2	B5, B6	M13	M15
S67	M1, M2, M3	B5, B6, B7	M13	M15
S68	M1	B5	M14	B9
S69	M1, M2	B5, B6	M14	B9
S70	M1, M2, M3	B5, B6, B7	M14	B9
S71	M1	B5	M14	M15
S72	M1, M2	B5, B6	M14	M15
S73	M1, M2, M3	B5, B6, B7	M14	M15
S74	M1	M7	B8	B9
S75	M1, M2	M7, M8	B8	B9
S76	M1, M2, M3	M7, M8, M9	B8	B9
S77	M1	M7	B8	M15
S78	M1, M2	M7, M8	B8	M15
S79	M1, M2, M3	M7, M8, M9	B8	M15
S80	M1	M7	M13	B9
S81	M1, M2	M7, M8	M13	B9
S82	M1, M2, M3	M7, M8, M9	M13	B9
S83	M1	M7	M13	M15
S84	M1, M2	M7, M8	M13	M15
S85	M1, M2, M3	M7, M8, M9	M13	M15
S86	M1	M7	M14	B9
S87	M1, M2	M7, M8	M14	B9
S88	M1, M2, M3	M7, M8, M9	M14	B9
S89	M1	M7	M14	M15
S90	M1, M2	M7, M8	M14	M15
S91	M1, M2, M3	M7, M8, M9	M14	M15
S92	M1	M10	B8	B9

S93	M1, M2	M10, M11	B8	B9
S94	M1, M2, M3	M10, M11, M12	B8	B9
S95	M1	M10	B8	M15
S96	M1, M2	M10, M11	B8	M15
S97	M1, M2, M3	M10, M11, M12	B8	M15
S98	M1	M10	M13	B9
S99	M1, M2	M10, M11	M13	B9
S100	M1, M2, M3	M10, M11, M12	M13	B9
S101	M1	M10	M13	M15
S102	M1, M2	M10, M11	M13	M15
S103	M1, M2, M3	M10, M11, M12	M13	M15
S104	M1	M10	M14	B9
S105	M1, M2	M10, M11	M14	B9
S106	M1, M2, M3	M10, M11, M12	M14	B9
S107	M1	M10	M14	M15
S108	M1, M2	M10, M11	M14	M15
S109	M1, M2, M3	M10, M11, M12	M14	M15
S110	M4	B5	B8	B9
S111	M4, M5	B5, B6	B8	B9
S112	M4, M5, M6	B5, B6, B7	B8	B9
S113	M4	B5	B8	M15
S114	M4, M5	B5, B6	B8	M15
S115	M4, M5, M6	B5, B6, B7	B8	M15
S116	M4	B5	M13	B9
S117	M4, M5	B5, B6	M13	B9
S118	M4, M5, M6	B5, B6, B7	M13	B9
S119	M4	B5	M13	M15
S120	M4, M5	B5, B6	M13	M15
S121	M4, M5, M6	B5, B6, B7	M13	M15
S122	M4	B5	M14	B9
S123	M4, M5	B5, B6	M14	B9
S124	M4, M5, M6	B5, B6, B7	M14	B9
S125	M4	B5	M14	M15
S126	M4, M5	B5, B6	M14	M15
S127	M4, M5, M6	B5, B6, B7	M14	M15
S128	M4	M7	B8	B9
S129	M4, M5	M7, M8	B8	B9
S130	M4, M5, M6	M7, M8, M9	B8	B9
S131	M4	M7	B8	M15
S132	M4, M5	M7, M8	B8	M15
S133	M4, M5, M6	M7, M8, M9	B8	M15
S134	M4	M7	M13	B9
S135	M4, M5	M7, M8	M13	B9
S136	M4, M5, M6	M7, M8, M9	M13	B9
S137	M4	M7	M13	M15
S138	M4, M5	M7, M8	M13	M15
S139	M4, M5, M6	M7, M8, M9	M13	M15
S140	M4	M7	M14	B9

S141	M4, M5	M7, M8	M14	B9
S142	M4, M5, M6	M7, M8, M9	M14	B9
S143	M4	M7	M14	M15
S144	M4, M5	M7, M8	M14	M15
S145	M4, M5, M6	M7, M8, M9	M14	M15
S146 = geometric improvement alternative	B1			

B. CHAPTER 1 APPENDIX: INTRODUCTION AND BACKGROUND TO THE PROBLEM

B.1 STATUS QUO OF STELLENBOSCH TRAFFIC CONGESTION

Table B.1: Status quo of Stellenbosch traffic congestion - results of the congestion quantification using probe data.

Speed reduction index

= [1– (actual travel speed / free-flow travel speed)] x 10

Congestion index

= [(actual travel time) – (free-flow travel time)] / [free-flow travel time]

Travel rate

= travel time / segment length

Delay rate

= (actual travel rate) – (acceptable travel rate)

Relative delay rate

= (delay rate) / (acceptable travel rate)

Delay ratio

= (delay rate) / (actual travel rate)

Route	Year	Speed Reduction Index		Congestion Index		Travel Rate		Delay Rate		Relative Delay Rate		Delay Ratio	
		am [a]	***pm*** [b]	***am***	***pm***	***am***	***pm***	***am***	***pm***	***am***	***pm***	***am***	***pm***
R304 Bottelary/Bird	2011	5.71	2.44	1.33	0.32	1.99	-	0.77	-	0.63	-	0.39	-
	2012	5.11	-	1.05	-	1.97	-	0.60	-	0.43	-	0.30	-
	2013	6.32	2.60	1.71	0.35	2.49	-	1.18	-	0.90	-	0.47	-
	2014	6.17	1.41	1.61	0.16	2.83	-	1.28	-	0.83	-	0.45	-
R304 Bird/Bottelary	2011	1.86	2.52	0.23	0.34	-	1.15	-	-0.08	-	-0.06	-	-0.07
	2013	1.33	2.97	0.15	0.43	-	1.33	-	-0.01	-	-0.004	-	-0.004
	2014	1.55	4.21	0.18	0.76	-	1.57	-	0.27	-	0.21	-	0.17
R44 Kromme Rhee/Bird	2011	4.12	1.68	0.70	0.20	1.39	-	0.22	-	0.19	-	0.16	-
	2012	4.32	-	0.76	-	1.37	-	0.26	-	0.23	-	0.19	-
	2013	5.14	1.61	1.06	0.19	1.70	-	0.52		0.44	-	0.31	-
	2014	6.52	2.54	1.88	0.34	2.17	-	1.09	-	1.01	-	0.50	-
R44 Bird/Kromme Rhee	2011	2.53	2.27	0.34	0.29	-	1.00	-	-0.10	-	-0.09	-	-0.10
	2013	2.21	2.04	0.28	0.26	-	1.04	-	-0.14	-	-0.12	-	-0.14
	2014	1.91	1.62	0.24	0.19	-	1.01	-	-0.20	-	-0.16	-	-0.20
R44 Annandale/Van Reede	2011	5.87	2.08	1.42	0.26	2.12	-	0.87	-	0.70	-	0.41	-
	2012	6.14	-	1.59	-	2.08	-	0.93	-	0.81	-	0.45	-
	2013	6.30	3.06	1.71	0.45	2.21	-	1.04		0.89	-	0.47	-
	2014	6.12	2.94	1.58	0.42	2.08	-	0.93	-	0.80	-	0.45	-
R44 Van Reede/Annandale	2011	2.24	3.41	0.29	0.53	-	1.34	-	0.08	-	0.06	-	0.06
	2013	2.73	3.70	0.38	0.60	-	1.41	-	0.14	-	0.11	-	0.10
	2014	3.21	4.32	0.47	0.77	-	1.48	-	0.28	-	0.23	-	0.19
R310 Baden Powell/Strand	2011	5.37	2.31	1.16	0.30	2.11	-	0.71	-	0.51	-	0.34	-
	2012	5.61	-	1.28	-	2.23	-	0.83	-	0.60	-	0.37	-
	2013	5.97	2.85	1.48	0.40	2.53	-	1.07		0.74	-	0.42	
	2014	3.15	3.04	0.46	0.44	1.38	-	0.03	-	0.02	-	0.02	-
R310 Strand/Baden Powell	2011	2.57	2.65	0.35	0.36	-	1.30	-	-0.07	-	-0.05	-	-0.05
	2013	2.48	2.56	0.33	0.35	-	1.25	-	-0.08	-	-0.06	-	-0.06
	2014	2.72	6.05	0.37	1.76	-	2.35	-	1.02	-	0.77	-	0.44
Adam Tas/Piet Retief via Dorp	2011	5.83	4.96	1.40	0.99	4.71	3.90	1.90	1.09	0.68	0.39	0.40	0.28
	2013	4.85	5.64	0.94	1.30	3.54	4.19	0.94	1.58	0.36	0.61	0.26	0.38
	2014	5.90	5.62	1.44	1.28	4.16	3.88	1.72	1.45	0.71	0.60	0.41	0.37
Piet Retief/Adam Tas via Dorp	2011	5.61	7.86	1.28	3.68	4.16	8.55	1.55	5.94	0.59	2.28	0.37	0.69
	2013	4.14	5.67	0.71	1.32	3.14	4.25	0.51	1.62	0.19	0.62	0.16	0.38
	2014	5.31	7.26	1.13	2.65	3.79	6.49	1.25	3.95	0.49	1.56	0.33	0.61
Bird/Van Reede via Piet Retief	2011	3.70	5.07	0.70	1.19	3.44	4.40	0.34	1.30	0.11	0.42	0.10	0.30
	2013	4.96	5.25	0.99	1.11	3.74	3.97	1.05	1.28	0.39	0.47	0.28	0.32
	2014	5.12	4.12	1.05	0.70	4.75	3.95	1.44	0.63	0.43	0.19	0.30	0.16
Van Reede/Bird via Piet Retief	2011	4.35	5.05	0.77	1.04	3.82	4.36	0.74	1.28	0.24	0.41	0.19	0.29
	2013	6.08	5.95	1.55	1.47	4.69	4.53	2.06	1.91	0.79	0.73	0.44	0.42
	2014	*-6.52*	*-3.66*	*-0.39*	*-0.27*	*3.82*	*4.62*	*-5.20*	*-4.40*	*-0.58*	*-0.49*	*-1.36*	*-0.95*
Bird/Van Reede via R44	2011	6.55	7.57	1.90	3.21	3.55	5.04	1.80	3.29	1.03	1.88	0.51	0.65
	2013	6.27	6.48	1.68	1.84	3.46	3.67	1.62	1.83	0.88	0.99	0.47	0.50
	2014	6.30	6.51	1.70	1.86	3.42	3.63	1.61	1.82	0.89	1.00	0.47	0.50
Van Reede/Bird via R44	2011	6.55	6.83	1.90	2.23	3.27	3.56	1.66	1.95	1.03	1.21	0.51	0.55
	2013	7.80	6.26	3.54	1.74	6.06	3.57	4.15	1.67	2.18	0.87	0.69	0.47
	2014	6.08	6.24	1.55	1.71	2.93	3.06	1.29	1.42	0.78	0.86	0.44	0.46

B.2 ETHICAL CLEARANCE FROM RESEARCH ETHICS COMMITTEE

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot • your knowledge partner

Approval Notice
New Application

24-Aug-2015
Ter Huurne, Dominique DA

Proposal #: SU-HSD-000699

Title: Travel characteristics of Stellenbosch University students and staff residing in the southern suburbs/towns of/to Stellenbosch.

Dear Miss Dominique Ter Huurne,

Your **New Application** received on **27-Jul-2015**, was reviewed
Please note the following information about your approved research proposal:

Proposal Approval Period: **13-Aug-2015 -12-Aug-2016**

Please take note of the general Investigator Responsibilities attached to this letter. You may commence with your research after complying fully with these guidelines.

Please remember to use your **proposal number** (**SU-HSD-000699**) on any documents or correspondence with the REC concerning your research proposal.

Please note that the REC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

Also note that a progress report should be submitted to the Committee before the approval period has expired if a continuation is required. The Committee will then consider the continuation of the project for a further year (if necessary).

This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki and the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health). Annually a number of projects may be selected randomly for an external audit.

National Health Research Ethics Committee (NHREC) registration number REC-050411-032.

We wish you the best as you conduct your research.

If you have any questions or need further help, please contact the REC office at 218089183.

Included Documents:

DESC Report - Ficker, Tanya

REC: Humanities New Application

Sincerely,

Clarissa Graham
REC Coordinator
Research Ethics Committee: Human Research (Humanities)

Investigator Responsibilities

Protection of Human Research Participants

Some of the general responsibilities investigators have when conducting research involving human participants are listed below:

1.Conducting the Research. You are responsible for making sure that the research is conducted according to the REC approved research protocol. You are also responsible for the actions of all your co-investigators and research staff involved with this research. You must also ensure that the research is conducted within the standards of your field of research.

2.Participant Enrollment. You may not recruit or enroll participants prior to the REC approval date or after the expiration date of REC approval. All recruitment materials for any form of media must be approved by the REC prior to their use. If you need to recruit more participants than was noted in your REC approval letter, you must submit an amendment requesting an increase in the number of participants.

3.Informed Consent. You are responsible for obtaining and documenting effective informed consent using **only** the REC-approved consent documents, and for ensuring that no human participants are involved in research prior to obtaining their informed consent. Please give all participants copies of the signed informed consent documents. Keep the originals in your secured research files for at least five (5) years.

4.Continuing Review. The REC must review and approve all REC-approved research proposals at intervals appropriate to the degree of risk but not less than once per year. There is **no grace period.** Prior to the date on which the REC approval of the research expires, **it is your responsibility to submit the continuing review report in a timely fashion to ensure a lapse in REC approval does not occur.** If REC approval of your research lapses, you must stop new participant enrollment, and contact the REC office immediately.

5.Amendments and Changes. If you wish to amend or change any aspect of your research (such as research design, interventions or procedures, number of participants, participant population, informed consent document, instruments, surveys or recruiting material), you must submit the amendment to the REC for review using the current Amendment Form. You **may not initiate** any amendments or changes to your research without first obtaining written REC review and approval. The **only exception** is when it is necessary to eliminate apparent immediate hazards to participants and the REC should be immediately informed of this necessity.

6.Adverse or Unanticipated Events. Any serious adverse events, participant complaints, and all unanticipated problems that involve risks to participants or others, as well as any research related injuries, occurring at this institution or at other performance sites must be reported to Malene Fouch within **five (5) days** of discovery of the incident. You must also report any instances of serious or continuing problems, or non-compliance with the RECs requirements for protecting human research participants. The only exception to this policy is that the death of a research participant must be reported in accordance with the Stellenbosch Universtiy Research Ethics Committee Standard Operating Procedures. All reportable events should be submitted to the REC using the Serious Adverse Event Report Form.

7.Research Record Keeping. You must keep the following research related records, at a minimum, in a secure location for a minimum of five years: the REC approved research proposal and all amendments; all informed consent documents; recruiting materials; continuing review reports; adverse or unanticipated events; and all correspondence from the REC

8.Provision of Counselling or emergency support. When a dedicated counsellor or psychologist provides support to a participant without prior REC review and approval, to the extent permitted by law, such activities will not be recognised as research nor the data used in support of research. Such cases should be indicated in the progress report or final report.

9.Final reports. When you have completed (no further participant enrollment, interactions, interventions or data analysis) or stopped work on your research, you must submit a Final Report to the REC.

10.On-Site Evaluations, Inspections, or Audits. If you are notified that your research will be reviewed or audited by the sponsor or any other external agency or any internal group, you must inform the REC immediately of the impending audit/evaluation.

B.3 INSTITUTIONAL PERMISSION FROM DIVISION OF INSTITUTIONAL RESEARCH AND PLANNING

UNIVERSITEIT • STELLENBOSCH • UNIVERSITY
jou kennisvennoot • your knowledge partner

17 July 2015

Ms Dominique ter Huurne
Transport Engineering Department
Stellenbosch University

Dear Ms ter Huurne

Concerning research project: *Travel characteristics of Stellenbosch University students and staff residing in the southern suburbs /towns of /to Stellenbosch*

The researcher has institutional permission to proceed with this project as stipulated in the institutional permission application. This permission is granted on the following conditions:

- The researcher must obtain ethical clearance before commencing with this study.
- Only the *SUrvey* software of Stellenbosch University (SU) may be used to solicit SU staff and student participation in the survey. The IT Division of the University can be contacted for support in the use of the *SUrvey* software.
- The e-mail addresses of SU staff and students cannot be provided directly to the researcher, but will be inserted into the survey tool (SUrvey) by an authorised person from the SU IT office.
- Participation is voluntary.
- Persons may not be coerced into participation.
- Persons who choose to participate must be informed of the purpose of the research, all the aspects of their participation, the risks to participation, their role in the research and their rights as participants. Participants must consent to participation. The researcher may not proceed until she is confident that all the before mentioned has been established and recorded.
- Persons who choose not to participate may not be penalized as a result of non-participation.
- Participants may withdraw their participation at any time, and without consequence.
- The data must be responsibly and suitably protected.
- The researcher must pay due diligence in seeing that the data is handled in the strictest confidence.
- Data must be collected and processed in a way that ensures the anonymity of all participants.
- The use of the collected data may not be extended beyond the purpose of this study.
- Individuals may not be identified in the report(s) or publication(s) of the results of the study.
- The privacy of individuals must be respected and protected.
- The researcher must conduct her research within the provisions of the Protection of Personal Information Act, 2013.

Best wishes,

I Cloete

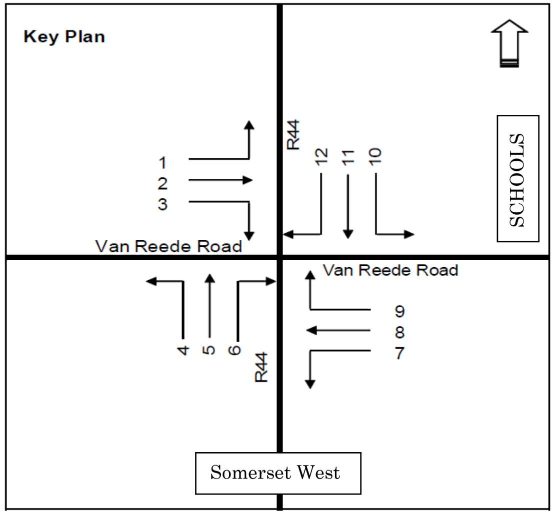
Prof Ian Cloete
Senior Director: Institutional Research and Planning

B.4 TRAFFIC COUNT COMPARISON AT R44 / VAN REEDE INTERSECTION FOR A SCHOOL DAY VS. A NON-SCHOOL DAY

Table B.2: Traffic count comparison at R44 / Van Reede intersection for a school day vs. a non-school day.

Time		Traffic Movements Thursday 4 April 2013 and Wednesday 10 April 2013																								Total	Total	Hourly Totals	Hourly Totals
Start	End	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12				
06:00	06:15	5	1	3	1	2	3	1	1	60	60	9	7	4	2			4	4	2	1	37	56		1	127	137		
06:15	06:30	5	3	2	3	6	9	2		105	106	35	21	13	10	2	1	2	3	2	1	71	54		1	245	212		
06:30	06:45	9	4	7	6	5	6	3	1	255	168	63	25	26	20	1	4	5	7	4	2	147	107	2	3	527	353		
06:45	07:00	2	4	9	10	11	12	5	7	304	276	154	55	52	32	7	3	8	4	4	1	242	204	2		800	608	1699	1310
07:00	07:15	7	7	42	38	8	10	29	11	459	365	207	83	117	55	8	2	14	8	37	6	267	94	4	4	1199	683	2771	1856
07:15	07:30	2	8	36	7	14	16	50	9	386	284	149	91	133	77	19	8	14	10	57	6	259	264	11	5	1130	785	3656	2429
07:30	07:45	5	5	19	22	16	13	71	10	326	242	139	90	181	117	13	10	30	18	31	15	257	261	7	1	1095	804	4224	2880
07:45	08:00	5	11	25	17	36	26	56	24	209	288	179	118	205	115	24	3	13	14	15	14	371	256	20	8	1158	894	4582	3166
08:00	08:15	5	9	33	28	21	25	19	13	246	284	156	120	152	85	14	8	16	18	18	7	315	238	12	6	1007	841	4390	3324
08:15	08:30	9	10	20	20	12	28	19	17	326	279	184	138	111	82	11	5	5	12	19	11	261	196	11	15	988	813	4248	3352
08:30	08:45	20	14	28	11	9	22	15	17	255	308	114	123	68	96	10	4	25	19	14	9	296	170	10	7	864	800	4017	3348
08:45	09:00	22	17	20	9	10	15	20	17	265	254	157	85	86	64	20	9	20	18	12	12	323	204	6	6	961	710	3820	3164
09:00	09:15	23	14	17	13	8	9	22	9	222	274	93	72	74	53	20	10	14	19	13	3	264	200	11	9	781	685	3594	3008
09:15	09:30	13	9	13	10	12	15	11	10	243	234	72	74	75	60	5	10	23	19	11	23	250	196	5	10	733	670	3339	2865
09:30	09:45	19	12	10	8	8	18	13	10	261	233	91	64	62	57	7	7	12	22	15	15	234	197	10	13	742	656	3217	2721
09:45	10:00	10	19	7	16	1	16	12	11	235	245	86	49	78	60	8	8	22	26	18	19	224	170	9	12	710	651	2966	2662
10:00	10:15	9	13	5	7	29	17	10	13	208	219	56	74	71	40	11	5	18	13	12	16	275	195	4	7	708	619	2893	2596
10:15	10:30	12	3	8	1	10	13	16	17	242	229	69	62	73	83	12	15	19	24	15	16	193	187	9	9	678	659	2838	2585
10:30	10:45	12	15	12	11	13	14	12	17	231	198	70	64	72	54	10	10	19	11	13	15	219	93	11	4	694	506	2790	2435
10:45	11:00	15	6	14	16	22	11	8	12	230	219	79	62	54	56	16	8	26	15	16	14	279	77	4	9	763	505	2843	2289
11:00	11:15	9	14	4	6	11	5	9	12	214	266	58	47	53	57	11	9	14	11	24	15	239	165	5	13	651	620	2786	2290
11:15	11:30	13	14	5	6	19	15	10	13	228	201	74	59	81	79	8	14	15	13	11	13	366	22	13	5	843	454	2951	2085
11:30	11:45	10	13	8	4	18	11	14	15	206	245	45	71	53	63	10	8	15	19	8	26	196	111	6	7	589	593	2846	2172
11:45	12:00	17	7	19	11	21	19	13	13	226	251	80	70	66	67	10	14	31	25	14	17	239	114	12	13	748	621	2831	2288
12:00	12:15	11	8	12	7	13	13	18	26	200	284	69	96	90	66	20	15	14	16	14	26	227	41	10	3	698	601	2878	2269
12:15	12:30	12	8	14	9	21	8	34	10	237	227	81	58	87	80	13	9	16	16	19	16	276	169	6	9	816	619	2851	2434
12:30	12:45	21	12	19	17	18	13	41	18	301	295	98	84	91	73	17	3	19	14	25	42	269	225	13	14	932	810	3194	2651
12:45	13:00	10	8	24	10	32	15	26	20	238	231	88	74	107	62	15	12	25	17	21	7	216	228	7	7	809	691	3255	2721
13:00	13:15	12	6	12	9	12	22	26	24	270	239	106	74	101	83	14	15	18	13	27	21	234	250	18	12	850	768	3407	2888
13:15	13:30	11	15	8	27	8	14	16	15	219	196	61	44	120	80	11	10	16	23	26	14	260	161	14	3	770	602	3361	2871
13:30	13:45	14	7	18	5	16	16	15	17	192	247	78	63	77	70	15	12	13	13	16	9	238	256	9	8	701	723	3130	2784
13:45	14:00	10	13	17	3	20	16	13	12	230	247	93	73	87	75	12	14	27	23	26	17	237	292	7	5	779	790	3100	2883
14:00	14:15	13	8	19	12	15	17	8	11	254	215	127	63	96	64	11	16	21	13	46	6	305	36	9	6	924	467	3174	2582
14:15	14:30	9	8	22	9	13	13	12	14	275	189	119	53	188	66	33	11	37	21	30	27	259	195	19	11	1016	617	3420	2597
14:30	14:45	14	10	16	8	21	21	13	13	209	217	71	46	179	65	37	11	32	12	21	12	249	169	5	12	867	596	3586	2470
14:45	15:00	1	8	12	3	6	9	16	19	212	228	87	75	57	60	6	6	17	16	30	28	233	172	2	10	679	634	3486	2314
15:00	15:15	9	9	15	3	15	10	12	17	368	199	79	55	137	92	20	9	23	21	26	19	318	169	6	5	1028	608	3590	2455
15:15	15:30	7	13	20	5	11	16	5	20	315	236	133	61	107	61	16	8	13	16	16	30	250	170	9	9	902	645	3476	2483
15:30	15:45	21	6	18	12	18	15	12	7	455	206	92	70	113	97	26	39	31	21	27	10	261	173	13	11	1087	667	3696	2554
15:45	16:00	8	7	9	7	18	18	12	18	276	221	109	73	189	104	38	13	40	21	22	22	204	283	10	8	935	795	3952	2715
16:00	16:15	11	15	11	10	24	19	8	11	331	269	103	69	120	118	21	19	15	18	20	19	305	254	7	15	976	836	3900	2943
16:15	16:30	9	18	24	13	14	13	16	36	516	331	90	99	100	102	9	19	11	17	24	19	357	260	8	7	1178	934	4176	3232

16:30	16:45	11	16	25	5	23	26	17	22	353	357	134	98	96	151	16	19	12	13	29	17	266	282	8	7	990	1013	4079	3578
16:45	17:00	8	7	25	8	25	20	24	25	629	321	209	113	193	115	28	17	15	15	35	26	377	236	11	8	1579	911	4723	3694
17:00	17:15	5	12	23	18	32	34	24	29	660	309	130	126	177	152	32	25	17	18	47	6	174	278	15	14	1336	1021	5083	3879
17:15	17:30	8	6	20	9	21	17	26	29	820	337	146	133	148	127	25	18	9	19	29	12	394	284	15	18	1661	1009	5566	3954
17:30	17:45	8	7	21	17	19	12	16	24	468	251	122	81	127	119	17	15	20	13	28	40	272	218	13	23	1131	820	5707	3761
17:45	18:00	9	3	22	9	12	23	14	17	420	258	132	70	110	82		17	16	9	22	19	315	252	9	20	1081	779	5209	3629
		510	462	792	516	749	748	864	733	14390	11838	4976	3575	4857	3648	709	527	861	750	1011	741	12320	8884	427	413				



C. CHAPTER 3 APPENDIX: RESEARCH DESIGN

C.1 HARD COPY OF SCHOOL TRAVEL SURVEY

- **This survey is completely anonymous.**
- **This survey must be completed by a parent, gaurdian, teacher or staff member of the relevant schools.**
- **The data from this survey will be used to determine the current trends in transport mode choice and factors influencing transport mode choice.**
- **The data will reveal key factors in addressing traffic congestion around schools in Stellenbosch.**
- **Important instructions are highlighted in yellow.**

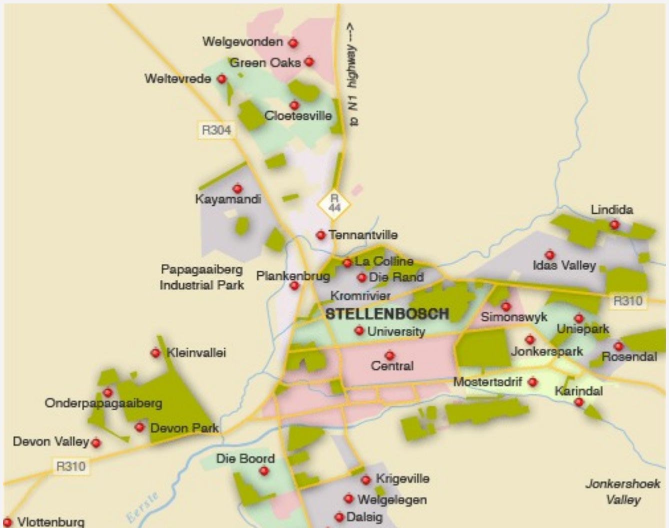
1. *Are you a staff member completing this survey?

- Yes
- No

2. *In which suburb do you live?

Please select 'Other' if you live outside of Stellenbosch and specify the town name.

- Arbeidslus
- Brandwacht
- Cloetesville
- Dalsig
- De Zalze
- Dennesig
- Die Boord
- Die Rant
- Idas Valley
- Jamestown
- Karindal
- Krigeville
- Kayamandi
- Kylemore
- Welbedaght
- La Colline
- Mostertsdrift
- Onderpappegaaiberg (Voëltjiesdorp)
- Paradyskloof
- Plankenburg
- Rozendal
- Simonswyk
- Technopark
- Tennantville
- Town Central
- Uniepark
- Universiteitsoord
- Other: Please Specify



3. **What is your household's annual income in Rand?**

- Less than R100 000
- R100 000 - 350 000
- R350 000 - 650 000
- R650 000 - 1 300 000
- More than R1 300 000

4. **How many school going children, specifically in Stellenbosch, are in your household?**

- 1
- 2
- 3
- 4
- 5

5. **Are all of the children in the household driven to school in the same car?**

If you choose YES, the mode of choice for all the children is car.

Examples:

1. If you have 3 school going children in the household, 2 drive to school in a car with mom, but 1 drives with dad, select NO
2. If you have 2 school going children in the household, 1 drives to school in a car with mom, but 1 walks to school, select NO
3. If you have 5 school going children in the household, all 5 children drive in a car with mom to school, select YES
4. If all of your school going children in the household make use of a bus service, select NO.

- Yes
- No

6. What is the gender of child 1?

- Male
- Female

7. Which school does child 1 attend?

- Bloemhof Girls' High School
- Eikestad Primary School
- Paul Roos Gymnasium
- Rhenish Girls' High School
- Rhenish Primary School
- Stellenbosch High School
- Stellenbosch Primary School
- Other: Please specify

8. What grade is child 1 in?

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12

9. Is child 1 a boarder at this school?

- Yes
- No

10. How often does child 1 come home?

- Every weekend
- Almost every weekend
- Sometimes
- Rarely
- Only during holidays

11. Which mode of transport does child 1 usually use to and from school?

Please select the mode of travel most used. In the case of a boarder, please select 'walking' or 'cycling', whichever is applicable.

- Car
- Bicycle
- Walking
- Private Bus service
- School Bus Service
- Train
- Scooter/ Motorcycle
- Taxi
- Other: Please specify

12. Why does child 1 use this mode of transport?

Please select as many options as applicable.

- School location near to residential area

- Expensive school bus fees

- No time to take children to school
- Walking or Cycling habit will maintain a good health
- Bicycle routes are safe to use
- School location is too far for children to walk or cycle
- Convenient and quick
- Reasonable school bus fees
- Child safety guaranteed
- Bus or Taxi driver negligence is worrisome
- Other: Please Specify

13. Who usually drives child 1 to school on a typical day?

- Mom
- Dad
- Lift Club
- Child
- Other: Please Specify

14. Does child 1 wear a helmet when cycling to school?

- Yes
- No

15. How far does child 1 have to travel to get to school?

- Less than 500m
- 500m to 1 km
- 1 to 1.6 km
- 1.6 to 2.5 km
- 2.5 to 5 km
- 5 to 10 km
- More than 10 km

16. How long does it take child 1 to make the trip to school in minutes?

- Less than 5 min
- 5 to 10 min
- 10 to 15 min
- 15 min to 20 min
- 20 to 30 min
- 30 to 45 min
- 45 to 60 min
- More than 60 min

17. What is the gender of child 2?

- Male
- Female

18. Which school does child 2 attend?

- Bloemhof Girls' High School
- Eikestad Primary School
- Paul Roos Gymnasium
- Rhenish Girls' High School
- Rhenish Primary School
- Stellenbosch High School
- Stellenbosch Primary School
- Other: Please specify

19. What grade is child 2 in?

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12

20. Is child 2 a boarder at this school?

- Yes
- No

21. How often does child 2 come home?

- Every weekend
- Almost every weekend
- Sometimes
- Rarely
- Only during holidays

22. Which mode of transport does child 2 usually use to and from school?

Please select the mode of travel most used. In the case of a boarder, please select 'walking' or 'cycling', whichever is applicable.

- Car
- Bicycle
- Walking
- Private Bus service
- School Bus Service
- Train
- Scooter/ Motorcycle
- Taxi
- Other: Please specify

23. Why does child 2 use this mode of transport?

Please select as many options as applicable.

- School location near to residential area

- [ ] Expensive school bus fees
- [ ] No time to take children to school
- [ ] Walking or Cycling habit will maintain a good health
- [ ] Bicycle routes are safe to use
- [ ] School location is too far for children to walk or cycle
- [ ] Convenient and quick
- [ ] Reasonable school bus fees
- [ ] Child safety guaranteed
- [ ] Bus or Taxi driver negligence is worrisome
- [ ] Other: Please Specify

24. Who usually drives child 2 to school on a typical day?

- Mom
- Dad
- Lift Club
- Child
- Other: Please Specify

25. Does child 2 wear a helmet when cycling to school?

- Yes
- No

26. How far does child 2 have to travel to get to school?

- Less than 500m
- 500m to 1 km
- 1 to 1.6 km
- 1.6 to 2.5 km
- 2.5 to 5 km
- 5 to 10 km
- More than 10 km

27. How long does it take child 2 to make the trip to school in minutes?

- Less than 5 min
- 5 to 10 min
- 10 to 15 min
- 15 min to 20 min
- 20 to 30 min
- 30 to 45 min
- 45 to 60 min
- More than 60 min

28. What is the gender of child 3?

- Male
- Female

29. Which school does child 3 attend?

- Bloemhof Girls' High School
- Eikestad Primary School
- Paul Roos Gymnasium
- Rhenish Girls' High School
- Rhenish Primary School
- Stellenbosch High School
- Stellenbosch Primary School
- Other: Please specify

30. What grade is child 3 in?

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12

31. Is child 3 a boarder at this school?

- Yes
- No

32. How often does child 3 come home?

- Every weekend
- Almost every weekend
- Sometimes
- Rarely
- Only during holidays

33. Which mode of transport does child 3 usually use to and from school?

Please select the mode of travel most used. In the case of a boarder, please select 'walking' or 'cycling', whichever is applicable.

- Car
- Bicycle
- Walking
- Private Bus service
- School Bus Service
- Train
- Scooter/ Motorcycle
- Taxi
- Other: Please specify

34. Why does child 3 use this mode of transport?

Please select as many options as applicable.

- School location near to residential area

- [ ] Expensive school bus fees
- [ ] No time to take children to school
- [ ] Walking or Cycling habit will maintain a good health
- [ ] Bicycle routes are safe to use
- [ ] School location is too far for children to walk or cycle
- [ ] Convenient and quick
- [ ] Reasonable school bus fees
- [ ] Child safety guaranteed
- [ ] Bus or Taxi driver negligence is worrisome
- [ ] Other: Please Specify

35. Who usually drives child 3 to school on a typical day?

- ○ Mom
- ○ Dad
- ○ Lift Club
- ○ Child
- ○ Other: Please Specify

36. Does child 3 wear a helmet when cycling to school?

Bicycle mode choice.

- ○ Yes
- ○ No

37. How far does child 3 have to travel to get to school?

- ○ Less than 500m
- ○ 500m to 1 km
- ○ 1 to 1.6 km
- ○ 1.6 to 2.5 km
- ○ 2.5 to 5 km
- ○ 5 to 10 km
- ○ More than 10 km

38. How long does it take child 3 to make the trip to school in minutes?

- ○ Less than 5 min
- ○ 5 to 10 min
- ○ 10 to 15 min
- ○ 15 min to 20 min
- ○ 20 to 30 min
- ○ 30 to 45 min
- ○ 45 to 60 min
- ○ More than 60 min

39. What is the gender of child 4?

- Male
- Female

40. Which school does child 4 attend?

- Bloemhof Girls' High School
- Eikestad Primary School
- Paul Roos Gymnasium
- Rhenish Girls' High School
- Rhenish Primary School
- Stellenbosch High School
- Stellenbosch Primary School
- Other: Please specify

41. What grade is child 4 in?

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12

42. Is child 4 a boarder at this school?

- Yes
- No

43. How often does child 4 come home?

- Every weekend
- Almost every weekend
- Sometimes
- Rarely
- Only during holidays

44. Which mode of transport does child 4 usually use to and from school?

Please select the mode of travel most used. In the case of a boarder, please select 'walking' or 'cycling', whichever is applicable.

- Car
- Bicycle
- Walking
- Private Bus service
- School Bus Service
- Train
- Scooter/ Motorcycle
- Taxi
- Other: Please specify

45. Why does child 4 use this mode of transport?

Please select as many options as applicable.

- School location near to residential area

- Expensive school bus fees

- No time to take children to school
- Walking or Cycling habit will maintain a good health
- Bicycle routes are safe to use
- School location is too far for children to walk or cycle
- Convenient and quick
- Reasonable school bus fees
- Child safety guaranteed
- Bus or Taxi driver negligence is worrisome
- Other: Please Specify

46. Who usually drives child 4 to school on a typical day?

Car mode choice selected

- Mom
- Dad
- Lift Club
- Child
- Other: Please Specify

47. Does child 4 wear a helmet when cycling to school?

Bicycle mode choice.

- Yes
- No

48. How far does child 4 have to travel to get to school?

- Less than 500m
- 500m to 1 km
- 1 to 1.6 km
- 1.6 to 2.5 km
- 2.5 to 5 km
- 5 to 10 km
- More than 10 km

49. How long does it take child 4 to make the trip to school in minutes?

- Less than 5 min
- 5 to 10 min
- 10 to 15 min
- 15 min to 20 min
- 20 to 30 min
- 30 to 45 min
- 45 to 60 min
- More than 60 min

50. What is the gender of child 5?

- Male
- Female

51. Which school does child 5 attend?

- Bloemhof Girls' High School
- Eikestad Primary School
- Paul Roos Gymnasium
- Rhenish Girls' High School
- Rhenish Primary School
- Stellenbosch High School
- Stellenbosch Primary School
- Other: Please specify

52. What grade is child 5 in?

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12

53. Is child 5 a boarder at this school?

- Yes
- No

54. How often does child 5 come home?

- Every weekend
- Almost every weekend
- Sometimes
- Rarely
- Only during holidays

55. Which mode of transport does child 5 usually use to and from school?

Please select the mode of travel most used. In the case of a boarder, please select 'walking' or 'cycling', whichever is applicable.

- Car
- Bicycle
- Walking
- Private Bus service
- School Bus Service
- Train
- Scooter/ Motorcycles
- Taxi
- Other: Please specify

56. Why does child 5 use this mode of transport?

Please select as many options as applicable.

- School location near to residential area

- Expensive school bus fees
- No time to take children to school
- Walking or Cycling habit will maintain a good health
- Bicycle routes are safe to use
- School location is too far for children to walk or cycle
- Convenient and quick
- Reasonable school bus fees
- Child safety guaranteed
- Bus or Taxi driver negligence is worrisome
- Other: Please Specify

57. Who usually drives child 5 to school on a typical day?

- Mom
- Dad
- Lift Club
- Child
- Other: Please Specify

58. Does child 5 wear a helmet when cycling to school?

Bicycle mode choice.

- Yes
- No

59. How far does child 5 have to travel to get to school?

- Less than 500m
- 500m to 1 km
- 1 to 1.6 km
- 1.6 to 2.5 km
- 2.5 to 5 km
- 5 to 10 km
- More than 10 km

60. How long does it take child 5 to make the trip to school in minutes?

- Less than 5 min
- 5 to 10 min
- 10 to 15 min
- 15 min to 20 min
- 20 to 30 min
- 30 to 45 min
- 45 to 60 min
- More than 60 min

61. Who usually drives the children to school on a typical day?

- Mom
- Dad
- Lift Club
- Child
- Other: Please Specify

62. *Please describe your trip sequence in the morning when taking the child/ children to school.

Please select the options applicable to you, and fill in the remaining blocks with 'None 1', 'None 2', etc.

From Home	
Bloemhof High School	
Eikestad Primary School	
Paul Roos Gymnasium	
Rhenish High School	
Rhenish Primary School	
Stellenbosch High School	
Stellenbosch Primary School	
To Work	
To Home	
None 1	
None 2	
None 3	
None 4	
To Other	

63. Is the above trip sequence taken to work en route or a detour?

Please select 'Detour' if the trip end is 'To Home'

- En route
- Detour

64. Why do your children use this mode of transport?

Please select as many options as applicable.

- School location near to residential area
- Expensive school bus fees
- No time to take children to school
- Walking or Cycling habit will maintain a good health
- Bicycle routes are safe to use
- School location is too far for children to walk or cycle
- Convenience and quick
- Reasonable school bus fees
- Child safety guaranteed
- Bus or Taxi driver negligence is worrisome
- Other: Please Specify

65. How far do you have to travel to make the aforementioned school trips?

- Less than 500m
- 500m to 1 km
- 1 to 1.6 km
- 1.6 to 2.5 km
- 2.5 to 5 km
- 5 to 10 km
- More than 11 km

66. How long does it take to make the aforementioned school trips, from home to when the last child is dropped off, in minutes?

- Less than 5 min
- 5 to 10 min
- 10 to 15 min
- 15 min to 20 min
- 20 to 30 min
- 30 to 45 min
- 45 to 60 min
- More than 60 min

67. *In summer, regardless of travel mode choice, what time does/ do the child/ children leave for school in the morning on a typical day?

- Before 07:00
- 07:00 - 07:15
- 07:15 - 07:30
- 07:30 - 07:45
- 07:45 - 08:00
- 08:00 - 08:15
- 08:15 - 08:30
- Later than 08:30

68. *In winter, regardless of travel mode choice, what time does/ do the child/ children leave for school in the morning on a typical day?

- Before 07:00
- 07:00 - 07:15
- 07:15 - 07:30
- 07:30 - 07:45
- 07:45 - 08:00
- 08:15 - 08:30
- Later than 08:30

69. What are the barriers preventing your child/ children from walking or cycling to school?

Please select as many options as applicable.

- ☐ Travelling distance too long
- ☐ Safety concerns with regard to traffic incidents
- ☐ Safety concerns with regard to mugging
- ☐ Bad weather
- ☐ Too much/ heavy baggage
- ☐ Does not like walking or cycling
- ☐ Few or no footways or paths
- ☐ Few or no pedestrian crossings along preferred route
- ☐ Other: Please Specify

70. Would your child/ children walk or cycle if there were no barriers?

- ○ Yes
- ○ No

71. What is your gender?

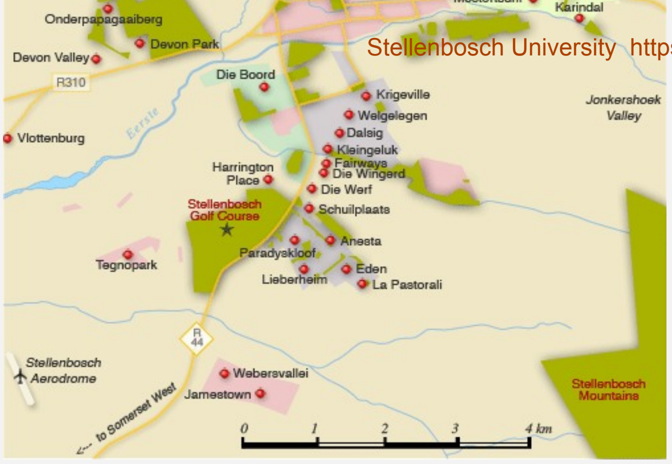
- ◯ Male
- ◯ Female

72. At which school do you work?

- ◯ Bloemhof Girls' High School
- ◯ Eikestad Primary School
- ◯ Paul Roos Gymnasium
- ◯ Rhenish Girls' High School
- ◯ Rhenish Primary School
- ◯ Stellenbosch High School
- ◯ Stellenbosch Primary School
- ◯ Other: Please specify

73. In which suburb do you live?

- ◯ Arbeidslus
- ◯ Brandwacht
- ◯ Cloetesville
- ◯ Dalsig
- ◯ De Zalze
- ◯ Dennesig
- ◯ Die Boord
- ◯ Die Rant
- ◯ Idas Valley
- ◯ Jamestown
- ◯ Karindal
- ◯ Krigeville
- ◯ Kayamandi
- ◯ Welbedaght
- ◯ La Colline
- ◯ Mostertsdrift
- ◯ Onderpappegaaiberg (Voëltjiesdorp)
- ◯ Paradyskloof
- ◯ Plankenburg
- ◉ Rozendal
- ◯ Simonswyk
- ◯ Technopark
- ◯ Tennantville
- ◯ Town Central
- ◯ Uniepark
- ◯ Universiteitsoord
- ◯ Other: Please Specify



74. What is your household's annual income in Rand?

- Less than R100 000
- R100 000 to 350 000
- R350 000 to 650 000
- R650 000 - 1 300 000
- More than R1 300 000

75. Which mode of travel do you use to get to school?

Please select the mode of travel most used.

- Car
- Bicycle
- Walking
- Private Bus service
- School Bus Service
- Train
- Scooter/ Motorcycles
- Taxi
- Other: Please Specify

76. Why do you use this mode of transport?

Please select as many options as applicable.

- School location near to residential area
- Expensive school bus fees
- Walking or Cycling habit will maintain a good health
- Bicycle routes are safe to use
- School location is too far to walk or cycle
- Convenient and quick
- Reasonable school bus fees
- Safety guaranteed
- Bus or Taxi driver negligence is worrisome
- Other: Please Specify

77. Do you wear a helmet when cycling to school?

Bicycle mode choice.

- Yes
- No

78. Do you usually drive yourself to and from school?

- Yes
- No

79. Who usually drops you off in the morning?

- Partner
- Lift Club
- Other: Please Specify

80. Please describe your trip sequence in the morning when taking the child/ children to school.

Please select the options applicable to you, and fill in the remaining blocks with 'None 1', 'None 2', etc.

From Home	
Bloemhof High School	
Eikestad Primary School	
Paul Roos Gymnasium	
Rhenish High School	
Rhenish Primary School	
Stellenbosch High School	
Stellenbosch Primary School	
To Work	
To Home	
-	
-	
-	
-	

81. Is the above trip sequence taken to work en route or a detour?

Please select 'Detour' if the trip end is 'To Home'

- ◯ En route
- ◯ Detour

82. How many people in total are usually in the car?

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10

83. *In summer, what time do you leave for school in the morning on a typical day?

- Before 07:00
- 07:00 - 07:15
- 07:15 - 07:30
- 07:30 - 07:45
- 07:45 - 08:00
- 08:00 - 08:15
- 08:15 - 08:30
- Later than 08:30

84. *In winter, what time do you leave for school in the morning on a typical day?

- Before 07:00
- 07:00 - 07:15
- 07:15 - 07:30
- 07:30 - 07:45
- 07:45 - 08:00
- 08:00 - 08:15
- 08:15 - 08:30
- Later than 08:30

85. How far do u have to travel to get to school?

- Less than 500m
- 500m to 1 km
- 1 to 1.6 km
- 1.6 to 2.5 km
- 2.5 to 5 km
- 5 to 10 km
- More than 10 km

86. How long does it take you to travel to school in minutes?

- Less than 5 min
- 5 to 10 min
- 10 to 15 min
- 15 min to 20 min
- 20 to 30 min
- 30 to 45 min
- 45 to 60 min
- More than 60 min

87. What are the barriers preventing you from walking or cycling to school?

- [ ] Travelling distance too long
- [ ] Safety concerns with regard to traffic incidents
- [ ] Safety concerns with regard to mugging
- [ ] Bad weather
- [ ] Too much/ heavy baggage
- [ ] Do not like walking or cycling
- [ ] Few or no footways or paths
- [ ] Few or no pedestrian crossings along preferred route
- [ ] Other: Please Specify

88. Would you walk or cycle if there were no barriers?

- Yes
- No

89. Regardless of travel mode choice, how does the traffic congestion in adjacent roads to the schools compare to that of the rest of Stellenbosch or the travelled route?

- a lot worse
- a little worse
- the same
- a little better
- a lot better

90. Please rate your frustration towards these traffic conditions.

no frustration — extreme frustration

1	2	3	4	5	6	7	8	9	10

91. Please rate the morning traffic congestion within a 1 km radius of the school.

very good/ free flow — extremely bad/ bumper-to-bumper

1	2	3	4	5	6	7	8	9	10

92. Please state any suggestions to improve the traffic congestion around schools in Stellenbosch. Questions are also welcome.

Thank you for taking the survey.

C.2 HARD COPY OF SU TRAVEL SURVEY

Page 1

1. This survey is completely anonymous and participation in the survey is absolutely voluntary.
2. Please read the information in the email carefully before completing this survey.

1. ***Please confirm that your daily trip to the *Stellenbosch University* campus entails travelling along the *R44* from the direction *Somerset West*.**

   Origins include Brandwacht Aan Rivier, Paradyskloof, James Town, De Zalze and all suburbs/towns beyond that.

   If you stay in a university residence or private flat/ house during the week, please select 'No, ...'.

   - Yes, I travel along the R44 from the direction Somerset West on a daily basis.
   - No, I do not travel along the R44 from the direction Somerset West on a daily basis.
     Your survey will end here.

2. ***Do you ever use *Annandale Rd./ Baden Powell Dr.* as an alternative route to at least part of the *R44* when the traffic congestion is bad?**
   - Yes
   - No

3. ***Are you a staff member?**
   - Yes
   - No

4. ***What is your gender?**
   - Female
   - Male

5. ***What is your field of work/ study?**
   - Arts and Social Sciences
   - Science
   - Education
   - AgriSciences
   - Law
   - Theology
   - Economic and Management Sciences
   - Engineering
   - Health Sciences
   - Other (please specify):

6. ***Are you an undergraduate or postgraduate student?**
   - Undergraduate
   - Postgraduate

7. ***Do you study/ work full-time or part-time?**
   - Full-time
   - Part-time

8. *Which mode of transportation do you typically use between home and the *Stellenbosch University* campus?

- Car (as driver)
- Car (as passenger)
- Bus
- Taxi
- Scooter/Motorcycle
- Bicycle
- Walking
- Other (please specify):

9. *Are you part of a lift club/ carpool?

- Yes
- No

10. *Would you consider carpooling if the university had an online platform that helps you find other students and/or staff members that reside near you?

- Yes
- No

11. *How many OTHER students/ staff members are part of this lift club?

- 1
- 2
- 3
- 4
- more than 4

12. *Is this trip to the *Stellenbosch University* campus en route to the final destination of the driver?

(I.e. if the purpose of the trip is merely to drop you off, please select 'No'.)

- Yes
- No

13. *Where do you park your car for the day?

If you have reserved parking (e.g. staff parking) please state so.

14. If the final destination of the driver is the *Stellenbosch University* campus, where does he/she park his/her car?

If he/she has reserved parking, please state so.

15. *Do you wear a helmet when cycling?

- Yes
- No

16. ***What is your travelling distance from home to the *Stellenbosch University* campus?**

- less than 1.6 km
- 1.6 to 2.5 km
- 2.5 to 5 km
- 5 to 10 km
- 10 to 20 km
- more than 20 km

17. ***On weekdays, at what time of the morning do you traverse the section of the *R44* between the *Stellenbosch Square* shopping mall and the *R44/ Van Reede Rd.* intersection?**

You need not traverse the complete section mentioned to answer this question.

(Please select an option at every time period. The total needs to add up to 5.)

	How many times per week?					
	0	1	2	3	4	5
before 07:00						
between 07:00 and 07:30						
between 07:30 and 08:00						
between 08:00 and 08:30						
between 08:30 and 09:00						
after 09:00						

18. ***Where do you go once you've reached the *R44/ Van Reede Rd.* intersection?**

- I continue straight on the R44.
- I turn right into Van Reede Rd.

19. ***Then, where do you go when you reach the *R44/ Dorp St. intersection?***

- I continue straight on the R44.
- I turn right into Dorp St.

20. ***Then, where do you go when you reach the traffic circle at *Kwikspar Paul Roos*?**

- I turn into Suidwal Rd. or Noordwal-Wes Rd. just after the circle.
- I drive on towards the Piet Retief St./ Dorp St. intersection and then pass Checkers and Mugg & Bean.
- Other (please specify):

21. *****Please rate the extent to which each of the following barriers prevent you from cycling to the *Stellenbosch University* campus on a daily basis.**

	do not prevent at all 1	2	somewhat prevent 3	4	prevent very strongly 5
do not own or have access to a bicycle.	○	○	○	○	○
travelling distance is too far.	○	○	○	○	○
safety concerns with regards to traffic collisions/ bad driver behaviour.	○	○	○	○	○
security concerns with regards to mugging.	○	○	○	○	○
route is too hilly/ steep.	○	○	○	○	○
too much and/ or heavy baggage.	○	○	○	○	○
few or no bicycle paths along the route.	○	○	○	○	○
few or no pedestrian crossings along the route.	○	○	○	○	○
no amenities (e.g. showers, secure bicycle sheds, locker facilities) at the final destination.	○	○	○	○	○
do not like cycling (irrespective of cycling distance).	○	○	○	○	○

22. *****Assuming that *"travelling distance is too far"* is the only barrier preventing you from cycling to the *Stellenbosch University* campus on a daily basis, what is the maximum acceptable distance you would be willing to cycle to the *Stellenbosch University* campus?**

Please give your answer in **kilometres**.

23. *****Regarding the statement: *"I support changes to cycling development and the provision of cycling facilities in Stellenbosch"*, do you...**

- ○ strongly agree
- ○ agree
- ○ neither agree nor disagree
- ○ disagree
- ○ strongly disagree

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24. ***Regardless of your travel mode choice, please rate the morning (07:00 to 08:00) traffic congestion within 2 km of the *Stellenbosch University* campus.**

- ◯ 1 | very good/ free flow
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10 | very bad / bumper-to-bumper

25. ***Please rate your frustration towards these traffic conditions.**

- ◯ 1 | no frustration
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10 | extreme frustration

Thank you for taking the time to complete this survey.

D. CHAPTER 4 APPENDIX: RESEARCH METHODOLOGY

D.1 SCHOOL SURVEY: LETTER TO THE PRINCIPALS

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

School's Address
5 September 2014

Faculty of Engineering
University of Stellenbosch
Cnr Banghoek Road & Joubert Street
Stellenbosch
7600

Dear Sir / Madam

Stellenbosch University Research Project: Traffic Congestion Related to School Travel

The Transportation Engineering Department of the University of Stellenbosch in conjunction with the Stellenbosch Smart Mobility Lab (SSML), a recently launched state-of-the-art facility that supports research and education in the field of Intelligent Transport Systems (ITS) at the university, is currently investigating the characteristics of school travel, its contribution to the town's recurrent congestion during morning peak hours and alternatives to improve this congestion in future.

The study requires data with regards to school learners' travel patterns, travel modes, travel times and travel origin. The study focuses on the schools located in Krigeville (Eikestad Primary, Rhenish Primary, Rhenish Girls' High, Bloemhof Girls' High and Paul Roos Gymnasium) and Mostertsdrift (Stellenbosch Primary and Stellenbosch High). The means to collect the aforementioned data is the completion of an electronic questionnaire by the parents and staff members of the numerous schools. This questionnaire is of a non-intrusive and anonymous nature. We believe that by gathering the necessary information, we could identify the causes of recurrent congestion in your schools' immediate vicinity and aim to relieve the problems at hand. Once the data have been collected and evaluated, they will be made available to each participating school.

We would like to acquire your permission to distribute the link to the research questionnaire (or hard copies where electronic copies are not a feasible option), and request your advice and support during this stage of the investigation.

The link to a sample of the survey is: ...
We will contact you in the upcoming week to schedule a meeting (approx. 30 minutes), which will allow you to obtain more detailed information concerning this survey and ask any questions you may have.

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

Thank you in advance for your co-operation.

Yours faithfully

……………………………………………..

Dr. SJ Andersen PhD (Stell)

Part time Lecturer: Intelligent Transport Systems
Office: S476
Phone: +27(0)21 808 2255
E-mail: jandersen@sun.ac.za

D.2 SCHOOL SURVEY: LETTER TO THE PARENTS

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

11 September 2014

Dear parents and staff members of (*school name*)

Stellenbosch University Research Project: Traffic Congestion Related to School Travel

The Transportation Engineering Department of the University of Stellenbosch in conjunction with the Stellenbosch Smart Mobility Lab (SSML), a recently launched state-of-the-art facility that supports research and education in the field of Intelligent Transport Systems (ITS) at the university, is currently investigating the characteristics of school travel. In particular, it is considering its contribution to the town's recurrent congestion during morning peak hours and will be investigating alternatives to improve this congestion in future.

The study requires data with regards to school learners' travel patterns, travel modes, travel times, travel origin, etc. We ask you, the parents and staff members of the school, to help us in our research by completing an electronic questionnaire. This survey is of a non-intrusive and anonymous nature, and is available in both Afrikaans and English. We believe that by gathering the necessary information, we can identify the causes of recurrent congestion in your schools' immediate vicinity and aim to relieve some of the problems at hand.

The research is undertaken by a Masters student in Transportation Engineering, Miss Dominique ter Huurne (15782492@sun.ac.za). She is supported by a final year student in Civil Engineering, Mr Ben Mong.

Please follow the link to the survey: https://sunsurveys.sun.ac.za/schooltravel.aspx. It will take you directly to the questionnaire, which only takes between 2 and 5 minutes to complete.

Your school supports this initiative and we trust that you will too.

Yours faithfully

Johann Andersen
Industry Associate Professor in Intelligent Transportation Systems

Fakulteit Ingenieurswese
•
Faculty of Engineering

Departement Siviele Ingenieurswese • Department of Civil Engineering

Privaatsak/Private Bag X1 • Matieland, 7602 • Suid-Afrika/South Africa
Tel: +27 21 808 4369/4352 • Faks/Fax: +27 21 808 4440
E-pos/E-mail: icm@sun.ac.za • Web: http://www.civeng.sun.ac.za

D.3 SU SURVEY: E-MAIL / INFORMATION SHEET SENT TO THE STUDY PARTICIPANTS

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

STELLENBOSCH UNIVERSITY
CONSENT TO PARTICIPATE IN RESEARCH

Travel characteristics of Stellenbosch University students and staff residing in the southern suburbs/towns of/to Stellenbosch.

You are asked to participate in a research study conducted by Dominique Andrea ter Huurne, M.Eng (Research) student from the Transportation Engineering Department at Stellenbosch University. The results of the research will contribute to the content of a master's thesis and journal publication. You were selected as a possible participant in this study, because you reside in the southern suburbs/towns of/to Stellenbosch.

1. PURPOSE OF THE STUDY

This research study forms part of a master's thesis that comprises a cost-benefit analysis of a hypothetical bicycle-sharing scheme for distance travellers in Stellenbosch. It is required for the evaluation of the mobility benefits (i.e. positive influence on traffic congestion) of the scheme. The data can, however, be used to evaluate the benefits of a modal shift from private motor vehicles to any other alternative and sustainable transportation mode.

2. PROCEDURES

If you volunteer to participate in this study, we would ask you to complete a ± 3-minute online survey.

3. POTENTIAL RISKS AND DISCOMFORTS

Participation in this research study does not expose you to any risks.

The only inconvenience borne by participating in this research study is the completion of the online survey.

4. POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

Participation in the research study does not result in any direct benefits to you.

The potential benefits to society are immense, however: the traffic congestion problem in Stellenbosch can be reduced. The traffic congestion in Stellenbosch has been quantified and is unsustainable for the future; it is thus in most of the resident's best interest to find a measure of congestion relief. The benefits to the users of the bicycle-sharing scheme is assessed in the thesis.

5. PAYMENT FOR PARTICIPATION

Participation in this research is voluntary and no remuneration will be paid out to you.

6. CONFIDENTIALITY

You are identifiable only by your email address. These addresses are never asked for again in the online survey though, and nor is any other form of identification. The only personal fact known about you is that you live in a suburb or town of/to Stellenbosch. There is thus no confidentiality that needs to be maintained during the research process. The email addresses will nevertheless be accessible only by the researcher and her supervisor, and will be disclosed only with your permission or as required by law.

The results will be published as part of the master's thesis referred to above and in a peer-reviewed journal article. Since all the results will be anonymous, no confidentiality needs to be maintained.

7. PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

8. IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact Ms. Dominique ter Huurne [15782492@sun.ac.za].

9. RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

D.4 STANDARD FORMAT OF THE ICA REPORTS IN VISUM

Table D.1: The standard format of the ICA report for signalised intersections.

Main Node no.			
	Control Type	Signalised	
	Method	HCM 2010	
	Average Delay		
	Average LOS		
Volume and Adjustments by Movement			
Approach	N, E, S or W		
Movement	L, T or R		
Base Volume	known from model, per movement		
PHF, Peak-hour factor	n.a.		
Peak 15 Volume	n.a.		
Adjusted Volume	n.a.		
Volume and Adjustments by Lane Group			
Approach	N, E, S or W		
Lane Group	L, C or R		
ID	per lane group		
Lanes	L, T, R or a combination of the three		
Control Type	No Right, permitted or protected		
V, Volume	from above, but per lane group		
P_{LT}, Proportion Left Turns	known from model		
P_{RT}, Proportion Right Turns	known from model		
Saturation Flow Rate			
Approach	N, E, S or W		
Lane Group ID	as above		
Control Type	as above		
s_0, Base Saturation Flow Rate	1900		
N, Number of Lanes	known from model		
f_w, Lane Width Adjustment	see **HCM 2010**, **Chapter 16**		
P_{HV}, % Heavy Vehicles	0		
f_{HV}, HV Adjustment	see **HCM 2010**, **Chapter 16**		
f_g, Grade Adjustment	see **HCM 2010**, **Chapter 16**		
f_p, Parking Adjustment	see **HCM 2010**, **Chapter 16**		
f_{bb}, Bus Blocking Adjustment	see **HCM 2010**, **Chapter 16**		
f_a, Area Type Adjustment	see **HCM 2010**, **Chapter 16**		
f_{LU}, Lane Utilization Adjustment	see **HCM 2010**, **Chapter 16**		
f_{RT}, Right Turn Adjustment	see **HCM 2010**, **Chapter 16**		
f_{LT}, Left Turn Adjustment	see **HCM 2010**, **Chapter 16**		
f_{Rpb}, Right Turn Ped. Adjustment	see **HCM 2010**, **Chapter 16**		
f_{Lpb}, Left Turn Ped. Adjustment	see **HCM 2010**, **Chapter 16**		
s, Saturation Flow Rate	$= s_0 \times N \times f_w \times f_{HV} \times f_g \times f_p \times f_{bb} \times f_a \times f_{LU} \times f_{RT} \times f_{LT} \times f_{Rpb} \times f_{Lpb}$		
Capacity, Control Delay, and Level of Service Determination			
Approach	N, E, S or W		
Lane Group	as above		
Control Type	as above		
V_i, Lane Group Volume	per phase within a cycle		
s, Saturation Flow Rate	from above		
g/C, Green / Cycle	from below		
c, Capacity	$= s \times \frac{g}{C}$		
X, Volume / Capacity	$= \frac{V}{c}$		
d_1, Uniform Delay	$= \frac{0.5\, C\, (1 - \frac{g}{C})^2}{1 - [\min(1, X) \frac{g}{C}]}$		
k, Delay Calibration Factor	= 0.5 for pretimed signals		
T, Analysis Period	1.0		
d_2, Incremental Delay	$= 900\mathrm{T}\left[(\mathrm{X}-1) + \sqrt{(X-1)^2 + \frac{8kIX}{cT}}\right]$		
d_3, Initial Queue Delay	0		
R_p, Platoon Ratio	default value of 1.00 for arrival type 3		
P, Proportion Arriving on Green	$= R_p \times \frac{g}{C}$		
PF, Progression Factor	default value of 1.00 for arrival type 3		
d_i, Lane Group Delay	$= d_1 + d_2$		
LOS	see ***Table 4.14***		
d_A, Approach Delay	$= \frac{\sum d_i V_i}{\sum V_i}$		
Approach LOS	see ***Table 4.14***		
d_I, Intersection Delay	$= \frac{\sum d_A V_A}{\sum V_A}$		
Intersection LOS	see ***Table 4.14***		

Back of Queue	
Approach	N, E, S or W
Arrival Type	set at 3, which means random arrivals in which the main platoon contains less than 40% of the lane group volume.
Lane Group	as above
g/C, Green / Cycle	from below
PF_2, Progression Factor	1, because R_p equals 1
Q_b, initial queue at start of analysis period	0
Q_1, First-term Queued	$= PF_2 \frac{\frac{V_L C}{3600}(1-\frac{g}{C})}{1-[\min(1, X_L)\frac{g}{C}]}$
Q_2, Second-term Queued	$= 0.25 c_L T \left[(X_L - 1) + \sqrt{(X_L-1)^2 + \frac{8k_B X_L}{c_L T} + \frac{16 k_B Q_{bL}}{(c_L T)^2}} \right]$
XU, Upstream V/C	ignored
I, Upstream Adj. Factor	1.0
k_B, Early Arrival Adj. Factor	$= 0.12 I (\frac{s_L g}{3600})^{0.7}$
Q, Average Back of Queue	$= Q_1 + Q_2$
p_1, first parameter for percentile back-of-queue factor	1.5, for pretimed signals and 90th percentile
p_2, second parameter for percentile back-of-queue factor	0.5, for pretimed signals and 90th percentile
p_3, third parameter for percentile back-of-queue factor	5, for pretimed signals and 90th percentile
$f_{B\%}$, % Factor	$= p_1 + p_2 e^{\frac{-Q}{p_3}}$
$Q_{\%}$ Percentile Back of Queue (veh)	$= Q \times f_{B\%}$
Signal Timing Information	
Approach	N, E, S or W
Lane Group	as above
Control Type	as above
Signal Type	permitted
C, Cycle Length	known from model
Gp, Minimum Pedestrian Timing	ignored
L, Total Loss Time per Cycle	
l_1, Start Up Loss Time	
l1p, Permitted Start Up Loss Time	
l_2, Clearance Loss Time	
Green Time Start	known from model
Green Time End	known from model
G, Actual Green Time	$= Green\ Time\ End - Green\ Time\ Start$
g_i, Effective Green Time	
Effective Green Time / Cycle Length	$= \frac{g_i}{C}$
Lane Group Volume / Saturation Flow Rate	$= \frac{V_i}{s_i}$
Critical Lane Group	see **HCM 2010, Chapter 16**

Right Turn Adjustment Factors for Permitted Phasing		
Approach	N, E, S or W	
Lane Group	as above	
Control Type	as above	
Subject is Single(S) or Multi(M)	known from model	
Opposed by Single(S) or Multi(M)	known from model	
C, Cycle Length	known from model	
G(s), Actual GT	as above	
g(s), Eff. perm. GT	as above	
g_o(s), Opposing Eff. GT	as above	
No, Number Lanes in Opposing Approach	known from model	
N, Number of Lanes in RT Lane Group	known from model	
V_{RT}, Adj. RT Flow Rate	from above	
P_{RT}, Proportion RT in Lane Group	from above	
RTC, Volume per Cycle	$= V_{RT} \times \frac{C}{3600}$	
V_o, Opposing Flow	from above	
t_L, Lost Time for opposing Lane Group	from above	
f_{LUo}, Opposing Lane Utilization	from above	
V_{orc}, Adjusted Opposing Flow per Cycle	$= \frac{V_o C}{3600}$	(opposed by single-lane approach)
	$= \frac{V_o C}{3600 N_o f_{LUo}}$	(opposed by multi-lane approach)
R_{po}, Opposing Platoon Ratio	as above	
g_f, Portion of g until Arrival of First RT Vehicle (for Shared Lanes)	$= G\left[e^{-0.86(RTC^{0.629})}\right] - t_R \;\; g_f \leq g \; (except\ excl. RT)$	(opposed by single-lane approach)
	$= G\left[e^{-0.882(RTC^{0.717})}\right] - t_R \;\; g_f \leq g \; (except\ excl. RT)$	(opposed by multi-lane approach)
q_{ro}, Opposing Queue Ratio	$= max\left[1 - R_{po}\left(\frac{g_o}{C}\right), 0\right]$	
g_q, Opposing Queue Clearing Time	$= 4.943 v_{orc}^{0.762} {q_{ro}}^{1.061} - t_L \;\; g_q \leq g$	(opposed by single-lane approach)
	$= \frac{v_{orc} q_{ro}}{0.5 - [v_{orc}(1 - q_{ro})/g_o]} - t_R, \; v_{orc}[(1 - q_{ro})/g_o] \leq 0.49$	(opposed by multi-lane approach)
g_u, Portion of g during which RT filter through Opposing Flow	$= g - g_q \;\; if\ g_q \geq g_f, or$ $= g - g_f \;\; if\ g_q < g_f$	
n, Maximumm Number of Opposing Vehicles that could Arrive during g_q - g_f.	$= max\left[\frac{g_q - g_f}{2}, 0\right]$	
P_{THo}, Proportion of TT and RT vehicles in Opposing Single-Lane Approach	$= 1 - P_{RTo}$	
v_{oe}, Effective Opposing Flow	$= \frac{V_o}{f_{LUo}}$	
E_{R1}, Through-car equivalents for permitted RT (veh/h/ln)	see page 16-124 in **HCM 2000**	
E_{R2}, Through-car equivalents for permitted RT (veh/h/ln)	$= max\left[\frac{(1 - P_{THo}^{n})}{P_{RTo}}, 1.0\right]$	
P_R, Proportion of RT Vehicles in Shared Lane	$= P_{RT}\left[1 + \frac{(N-1)g}{\left(g_f\, {}^{g_u}/_{E_{R1}} + 4.24\right)}\right]$	
f_{min}	$= \frac{2(1 + P_{RT})}{g}$	
g_{diff}	$= max[g_q - g_f, 0] \;\; (except\ when\ RT\ volume\ is\ 0.)$	
f_m, Right Turn Adjustment for Lane	$= \frac{g_f}{g} + \left[\frac{g_u/g}{1 + P_{LT}(E_{R1} - 1)}\right] + \left[\frac{g_{diff}/g}{1 + P_{LT}(E_{R2} - 1)}\right]$	(opposed by single-lane approach)
	$= \frac{g_f}{g} + \frac{g_u}{g}\left[\frac{1}{1 + P_{RT}(E_{R1} - 1)}\right]$	(opposed by multi-lane approach)
f_{RT}, Right Turn Adjustment for Total Lane Group	$= f_m$	(opposed by single-lane approach)
	$= \frac{f_m + 0.91(N-1)}{N}$	(opposed by multi-lane approach)

Table D.2: The standard format of the ICA report for roundabouts.

Node No.			
	Control Type	Roundabout	
	Method	HCM 2010	
	Average Delay		
	Average LOS		
	Worst Case Delay		
	Worst Case LOS		
Volume by Movement			
Approach	N, E, S or W		
Movement	L, T or R		
Base Volume (veh/h)	known from model, per movement		
PHF	n.a.		
Volume, Lane Flow Rate (veh/h)	n.a.		
Volume			
Approach	N, E, S or W		
Lane no.	e.g. Lane 1		
Movements per Lane	L, C or R		
Volume, Lane Flow Rate (veh/h)	from above, but per lane		
P_{HV}, Share of Heavy Vehicles	0		
f_{HV}, Heavy-Vehicle Adjustment Factor	0		
Adjusted Volume (pc/h)	n.a.		
Is Bypass Lane	no bypasses considered		
Uses Bypass			
Bypass Type			
Bypass Volume (pc/h)			
Non-Bypass Volume (pc/h)	as above		
Capacity			
Approach	as above		
Lane no.	as above		
Movements per Lane	as above		
v_e, Entry Volume (pc/h)	as above		
v_{bypass}, Bypass Volume (pc/h)	0		
A, Capacity Calibration Factor	= 1,130, see pg. 21-6 and 21-7 in HCM 2010		
B, Capacity Calibration Factor	= 0.001, see pg. 21-6 and 21-8 in HCM 2010		
v_c, Conflicting Volume (pc/h)	from above, see pg. 21-12 and 21-13 in HCM 2010		
$v_{ex,pce}$, Conflicting Volume for Bypass Lane (pc/h)	0		
c_{pce}, Capacity (pc/h)	$= Ae^{-Bv_c}$		
n_ped, Conflicting Pedestrian Volume			
f_{ped}, Pedestrian Adjustment Factor			
P_{HV}, Share of Heavy Vehicles			
f_{HV}, Heavy-Vehicle Adjustment Factor			
c, Capacity (veh/h)	as above		
Delay and Level of Service by Lane			
Approach	as above		
Lane	as above		
Movements	as above		
v_i, Volume, Lane Flow Rate (veh/h)	as above		
c, Capacity (veh/h)	from above		
x, Volume-to-Capacity Ratio	$= \frac{v}{c}$		
T, Analysis Period	1.0		
Q_{95}, 95% Queue Length (veh)	$= 900\mathrm{T}\left[(\mathrm{x}-1) + \sqrt{(1-x)^2 + \frac{\left(\frac{3600}{c}\right)x}{150T}}\right]\left(\frac{c}{3600}\right)$		
d_i, Delay per Lane (s/veh)	$= \frac{3600}{c} + 900\mathrm{T}\left[(x-1) + \sqrt{(x-1)^2 + \frac{\left(\frac{3600}{c}\right)x}{450T}}\right] + 5 \times \min[x, 1]$		
LOS	see ***Table 4.15***		
d_A, Approach Delay (s/veh)	$= \frac{\sum d_i v_i}{\sum v_i}$		
Approach LOS	see ***Table 4.15***		
Delay and Level of Service by Movement			
Approach	same formulas as per lane, volumes are just per movement		
Movement			
v, Volume, Lane Flow Rate (veh/h)			
c, Capacity (veh/h)			
x, Volume-to-Capacity Ratio			
d, Delay (s/veh)			
LOS			
d_A, Approach Delay (s/veh)			
Approach LOS			
d_I, Intersection Delay (s/veh)	$= \frac{\sum d_A V_A}{\sum V_A}$		
Intersection LOS	see ***Table 4.15***		

Table D.3: The standard format of the ICA report for two-way stops.

Node No.			
	Control Type	TWSC	
	Method	HCM 2010	
	dI, Average Delay		
	Worst Case Delay		
	Worst Case LOS		
Volume and Adjustments			
Approach	N, E, S or W		
Movement	L, T or R		
Base Volume	known from model, per movement		
PHF, Peak-hour factor	n.a.		
V, Adjusted Volume	n.a.		
Pedestrians			
Approach	ignored		
Movement			
v_x, Flow (Ped/hr)			
w, Lane Width (m)			
S_p, Walking Speed (m/s)			
f_{pb}, Percent Blockage			
Capacity of Movements below Rank 1			
Approach	as above		
Movement	as above		
Rank	see **HCM 2010, Chapter 19**		
v_x, Volume of Movement x	from above		
Conflicting Volume (Veh)	combinations of volumes from above, see **HCM 2010, Chapter 19**		
Conflicting Volume (Ped)	ignored		
Conflicting Volume			
Two-Stage Gap Acceptance	no		
Number of Storage Spaces in Median Refuge Area	n.a.		
c_{px}, Potential Capacity of Movement x	$= v_{c,x} \dfrac{e^{-v_{c,x} t_{c,x}/3600}}{1 - e^{-v_{c,x} t_{f,x}/3600}}$		
$c_{m,x}$, Capacity of Movement x	formula dependent on rank, see **HCM 2010, Chapter 19**		
Critical Headway and Follow Up Headway			
Approach	as above		
Movement	as above		
$t_{c,x,base}$, Base Critical Headway	see page 19-15 in **HCM 2010**		
$t_{c,x,base,I}$, Base Critical Headway (Stage I)	n.a.		
$t_{c,x,base,II}$, Base Critical Headway (Stage II)			
$t_{c,x,HV}$, Heavy Vehicles Adjustment Factor	see page 19-15 in **HCM 2010**		
P_{HV}, % Heavy Vehicles	0		
$t_{c,x,G}$, Grade Adjustment Factor	see page 19-15 in **HCM 2010**		
G, % Grade	known from model		
$t_{3,x,RT}$, Geometry Adjustment Factor	see page 19-15 in **HCM 2010**		
$t_{c,x}$, Critical Headway	$= t_{c.x.base} + t_{c.x.HV} P_{HV.x} + t_{c.x.G} G - t_{3.x.RT}$		
$t_{c,x,I}$, Critical Headway (Stage I)	n.a.		
$t_{c,x,II}$, Critical Headway (Stage II)			
$t_{f,x,base}$, Base Follow-Up Headway	see page 19-16 in **HCM 2010**		
$t_{f,x,hv}$, Heavy Vehicles Adjustment Factor	see page 19-16 in **HCM 2010**		
$t_{f,x}$, Follow-Up Headway	$= t_{f,x,base} + t_{f,x,HV} P_{HV,x}$		

Delay and Level of Service by Movement	
Approach	as above
Movement	as above
v_x, Volume of Movement x	as above
$c_{m,x}$, Capacity	as above
X_x,Volume / Capacity of Movement x	$= \frac{v_x}{c_{mx}}$
T, Analysis Period	1.0
d_x, Delay of Movement x	$= \frac{3600}{c_{m,x}} + 900T\left[X_x - 1 + \sqrt{(X_x) + \frac{\left(\frac{3600}{c_{m,x}}\right)(X_x)}{450T}}\right] + 5$
LOS	see ***Table 4.15***
d_A, Approach Delay	$= \frac{\sum d_x v_x}{\sum v_x}$
Approach LOS	see ***Table 4.15***
d_{Rank1}, Rank 1 Delay	ignored, see page 19-28 in **HCM 2010**
Delay and Level of Service by Lane	
Approach	as above
Lane no.	e.g. Lane 1
Movements	as above
v_l, Volume of Lane *l*	as above, but per lane
$c_{m,l}$, Capacity of Lane *l*	$= \frac{\sum v_x}{\sum X_x}$
X_l, Volume / Capacity of Lane *l*	$= \frac{v_l}{c_{ml}}$
Q_{95}, 95% Queue Length	$= 900T\left[\frac{v_l}{c_{m,l}} - 1 + \sqrt{\left(\frac{v_l}{c_{m,l}} - 1\right)^2 + \frac{\left(\frac{3600}{c_{m,l}}\right)\left(\frac{v_l}{c_{m,l}}\right)}{150T}}\right] + \left(\frac{c_{m,l}}{3600}\right)$
d_l, Delay for Lane *l*	same formula as for d_x
LOS	see ***Table 4.15***
d_A, Approach Delay	as above
Approach LOS	as above
d_I, Intersection Delay (s/veh)	$= \frac{\sum d_A V_A}{\sum V_A}$
Intersection LOS	see ***Table 4.15***

E. CHAPTER 5 APPENDIX: PREVAILING TRAFFIC CONDITIONS AND MODEL CALIBRATION

E.1 NUMBERING SYSTEM USED TO PRESENT THE RESULTS OF THE 2015 TRAFFIC VOLUME COUNT STUDY

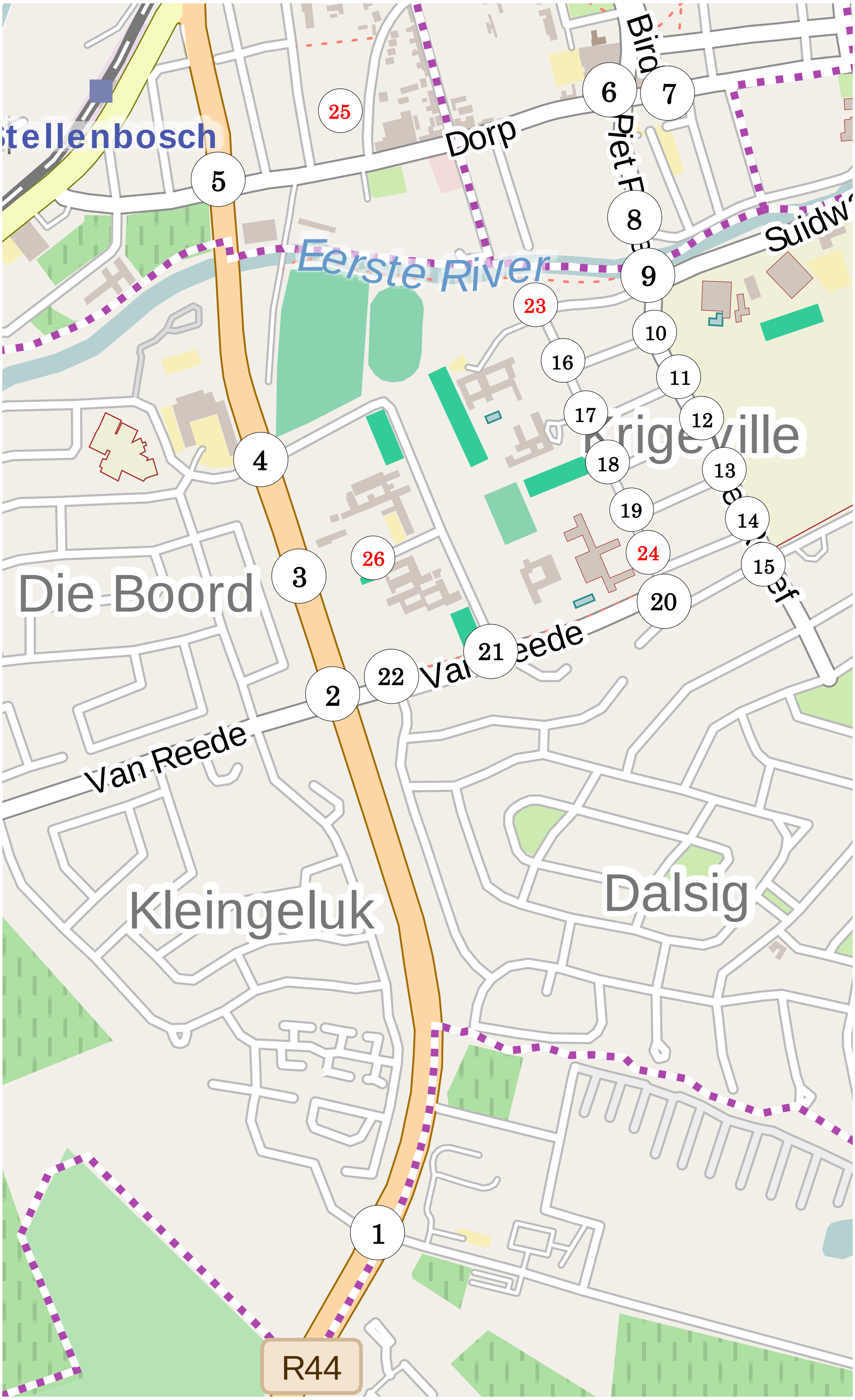
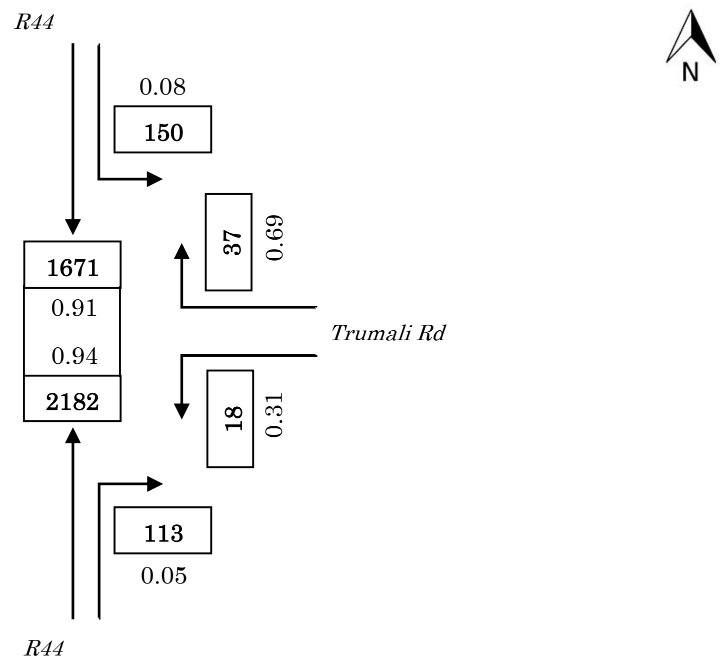
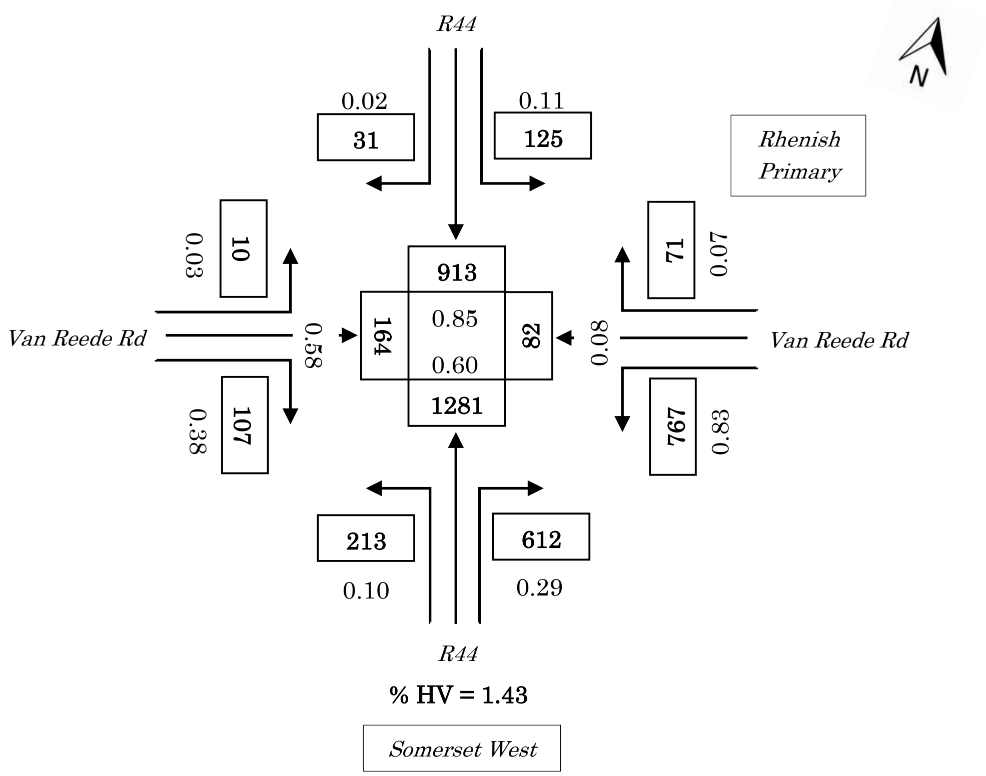


Figure E.1: The numbering system for the intersections in the study area at which traffic counts were conducted.

E.2 RESULTS: TRAFFIC VOLUME COUNTS

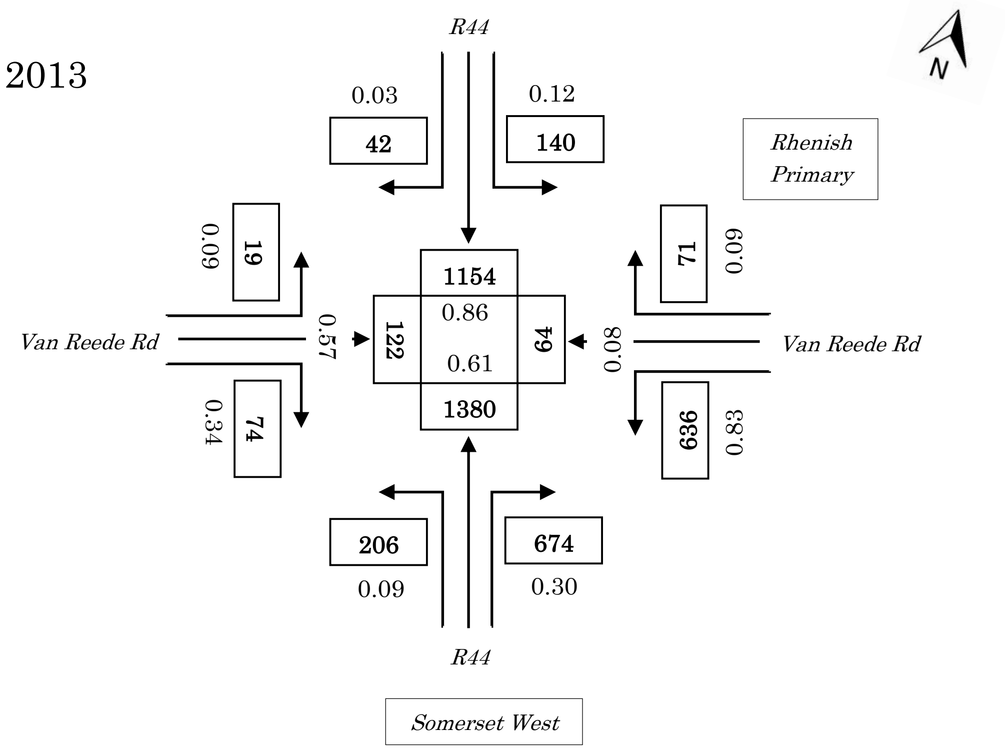
Table E.1: The adjusted AM peak-hour volumes for every movement at each of the intersections in the study area.

<table>
<tr><td>1</td><td>
</td></tr>
<tr><td>2a

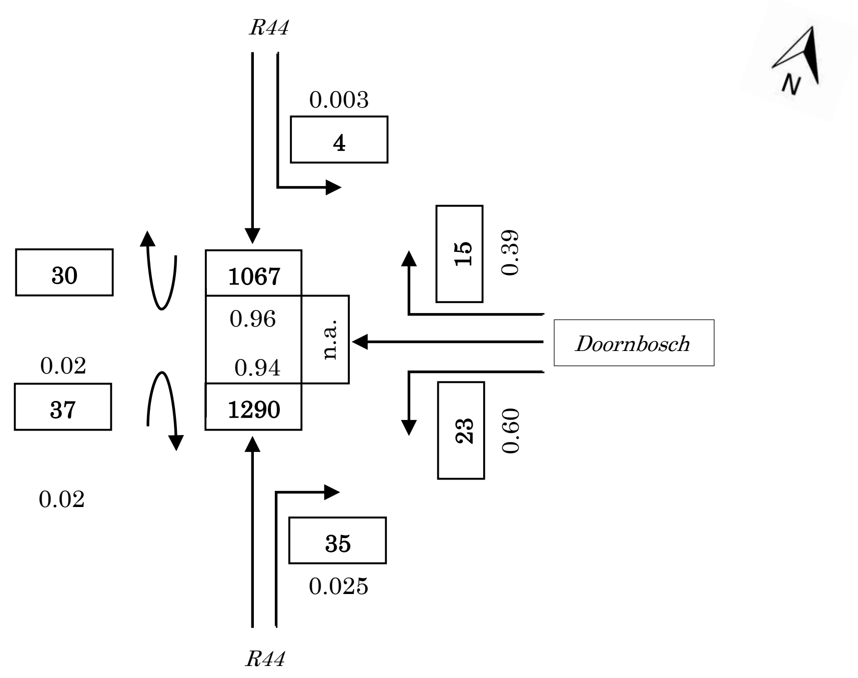
(PHF = 0.97)</td><td>
</td></tr>
</table>

2b

(PHF = 0.96)

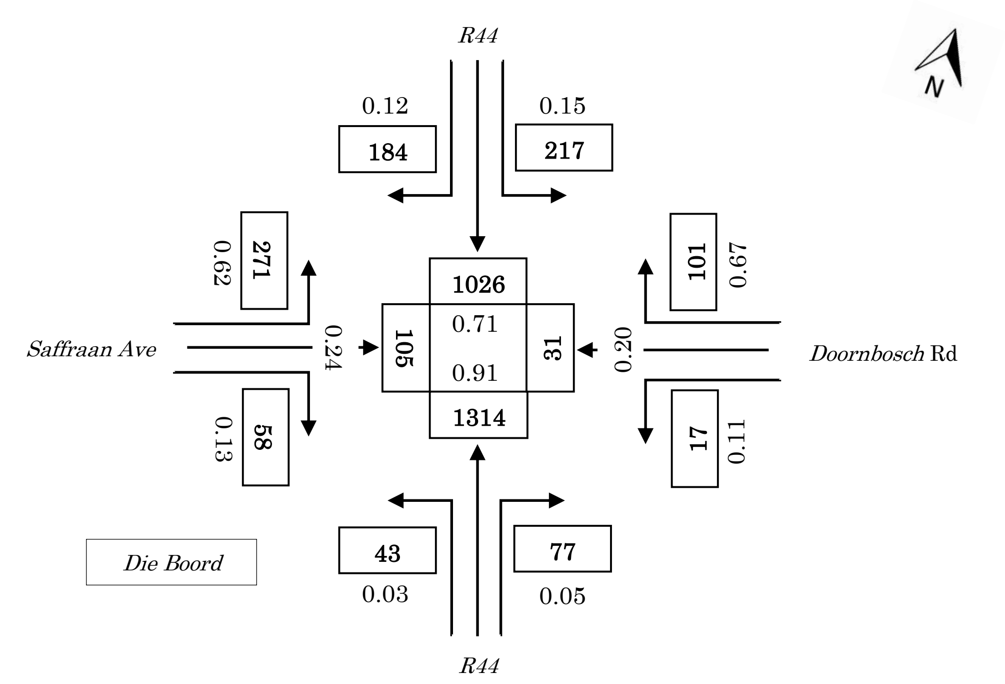

2013
R44
0.03
42
0.12
140
Rhenish Primary
0.09
19
71
0.09
1154
0.86
0.61
1380
122
64
Van Reede Rd
0.57
0.08
Van Reede Rd
0.34
74
636
0.83
206
0.09
674
0.30
R44
Somerset West
N

3


R44
0.003
4
N
30
1067
0.96
0.94
1290
n.a.
15
0.39
Doornbosch
0.02
37
23
0.60
0.02
35
0.025
R44

4a

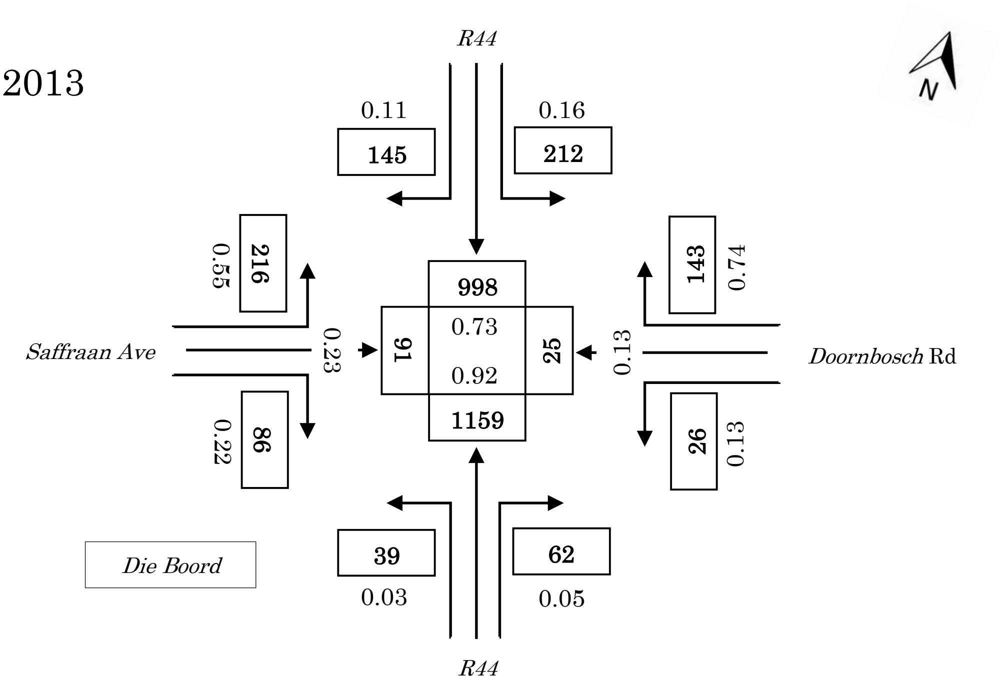
(PHF = 0.88)



4b

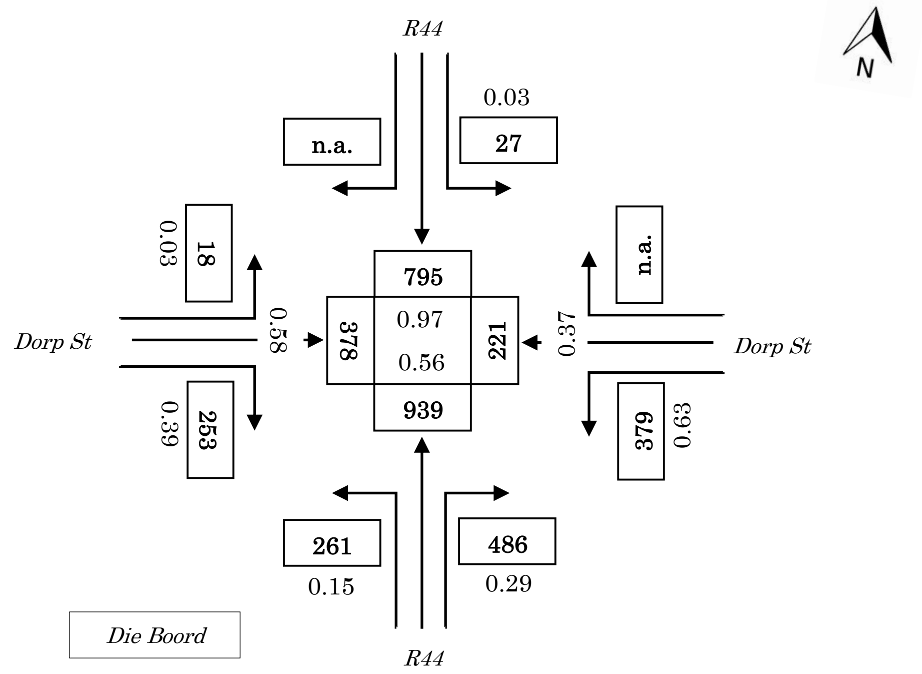
(PHF = 0.85)

2013



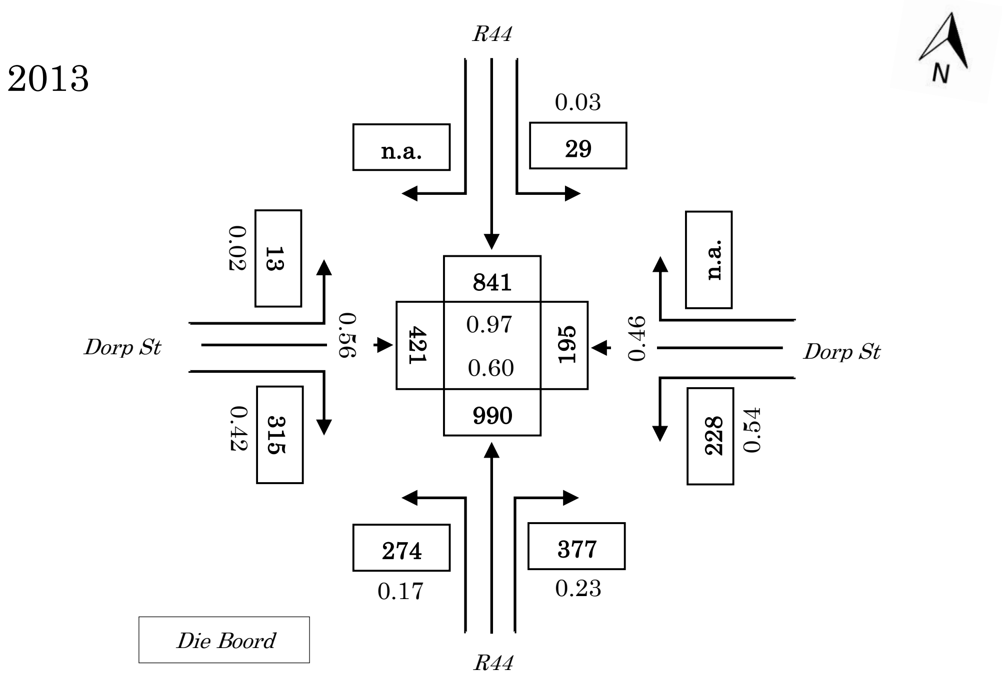
5a

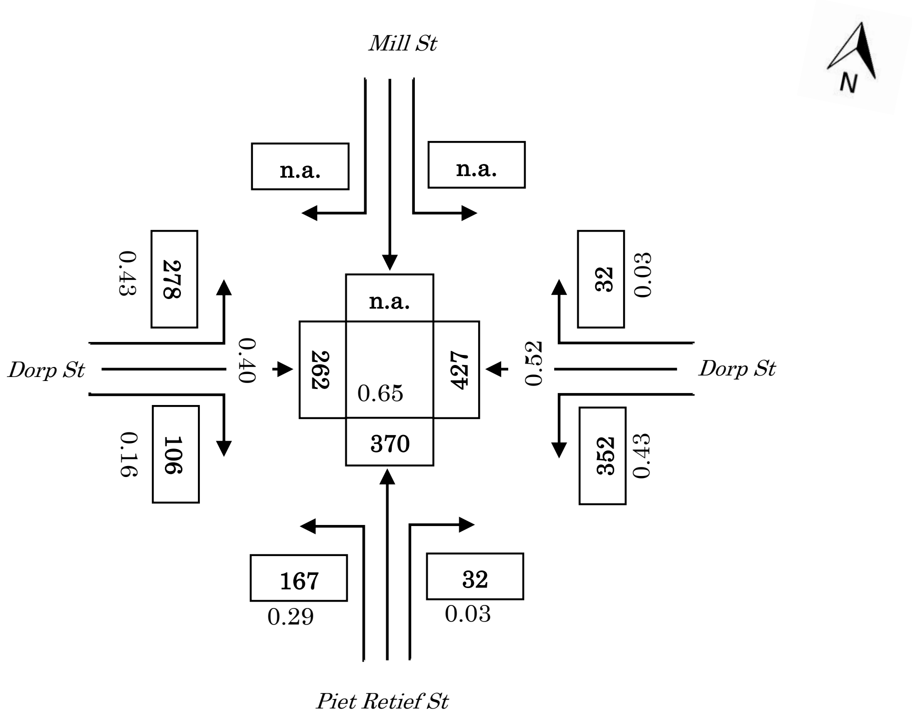
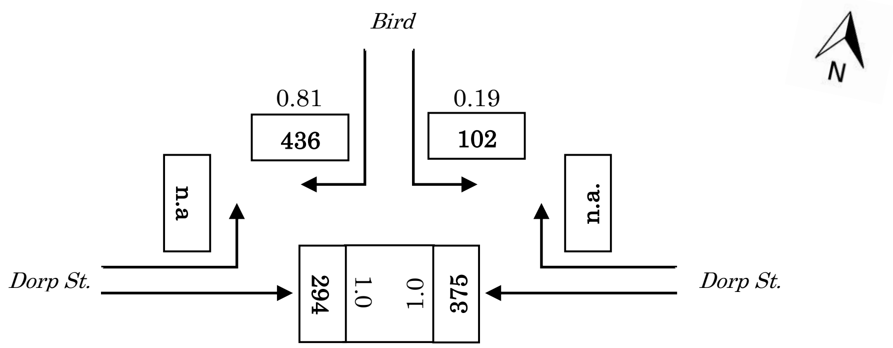
(PHF = 0.96)



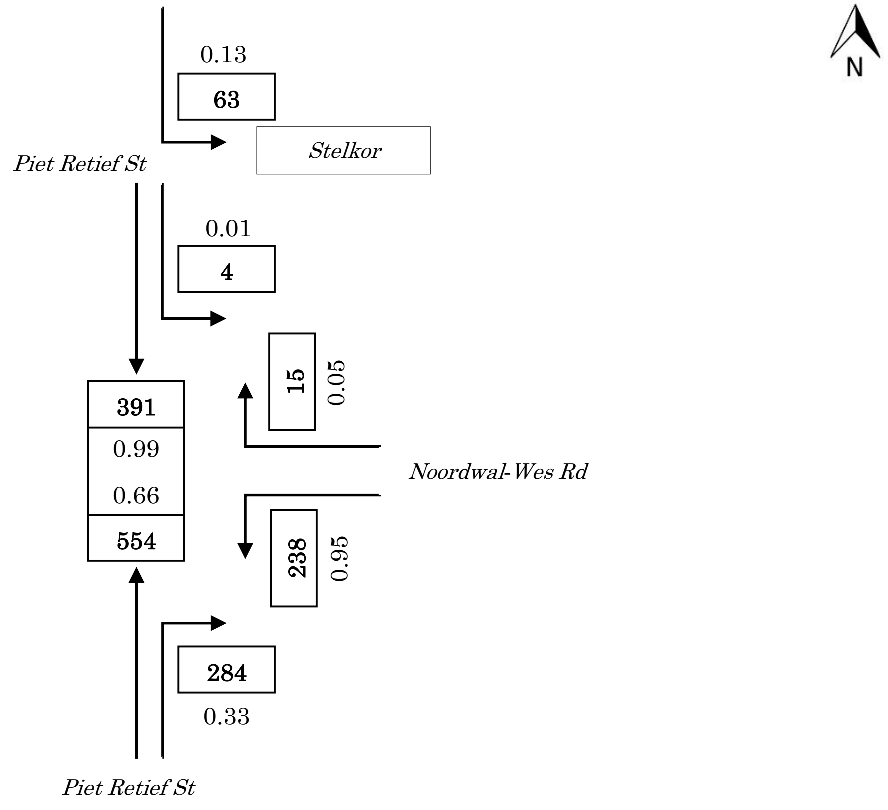
5b

(PHF = 0.88)
(for 07:15 to 08:15)



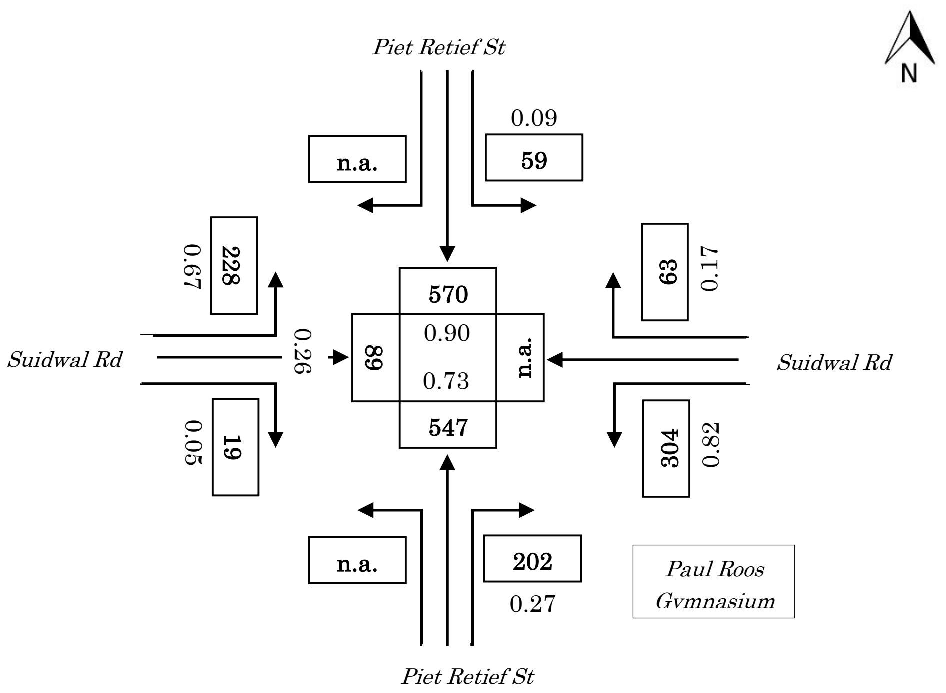
<u>6</u>	
<u>7</u> (PHF = 0.96)	

8

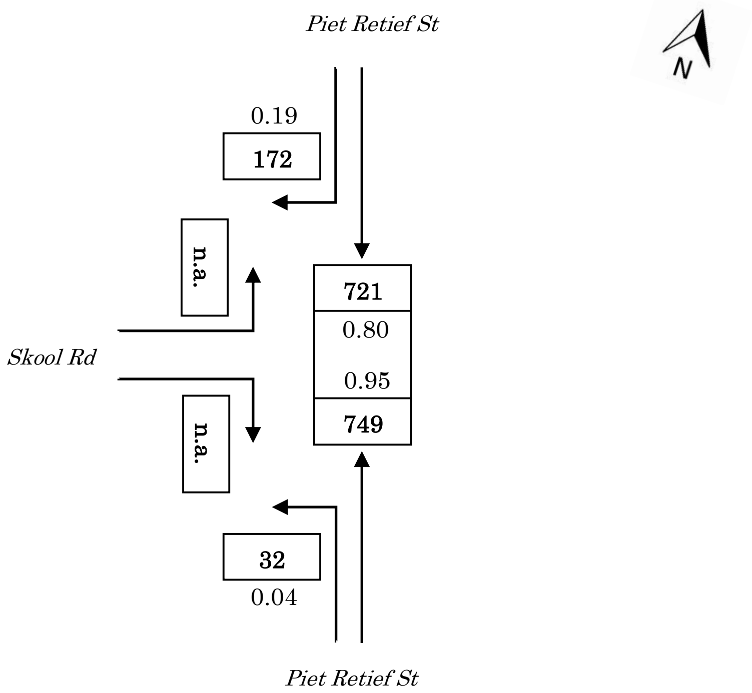

N
0.13
63
Stelkor
Piet Retief St
0.01
4
15
0.05
391
0.99
0.66
554
Noordwal-Wes Rd
238
0.95
284
0.33
Piet Retief St

9

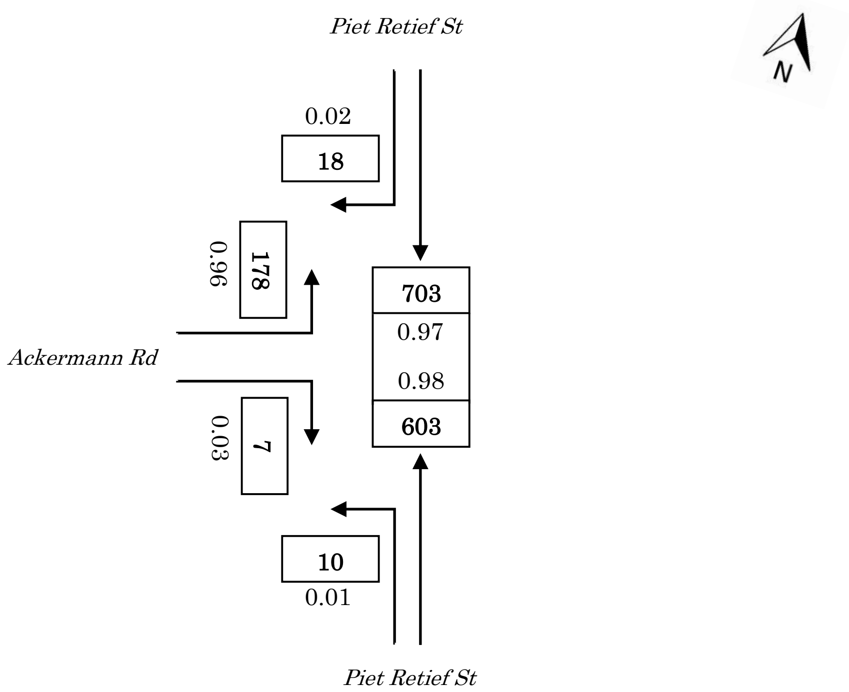
(PHF = 0.93)


Piet Retief St
N
n.a.
0.09
59
0.67
228
63
0.17
570
0.90
0.73
547
68
n.a.
0.26
Suidwal Rd
Suidwal Rd
0.05
19
304
0.82
n.a.
202
0.27
Paul Roos
Gymnasium
Piet Retief St

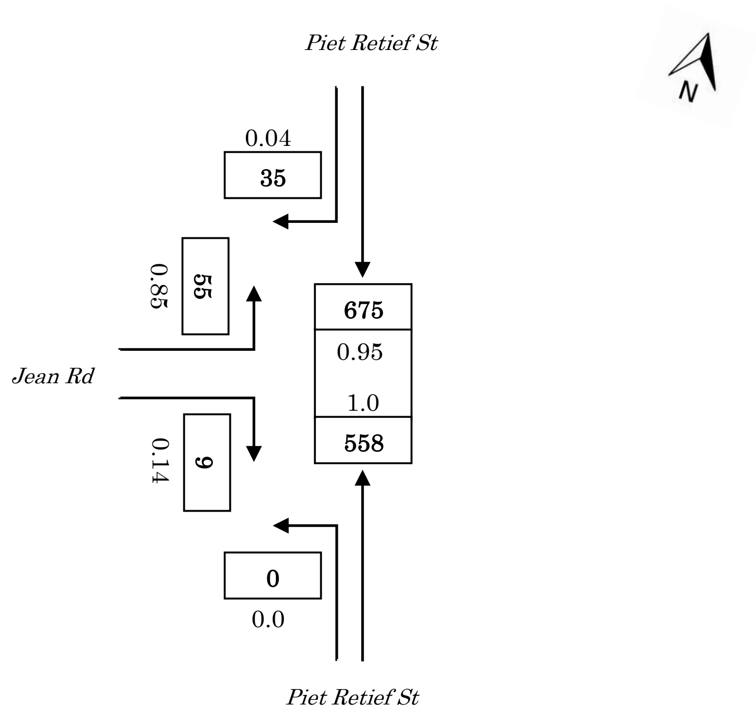
10


Piet Retief St
0.19
172
n.a.
721
0.80
Skool Rd
0.95
749
n.a.
32
0.04
Piet Retief St
N

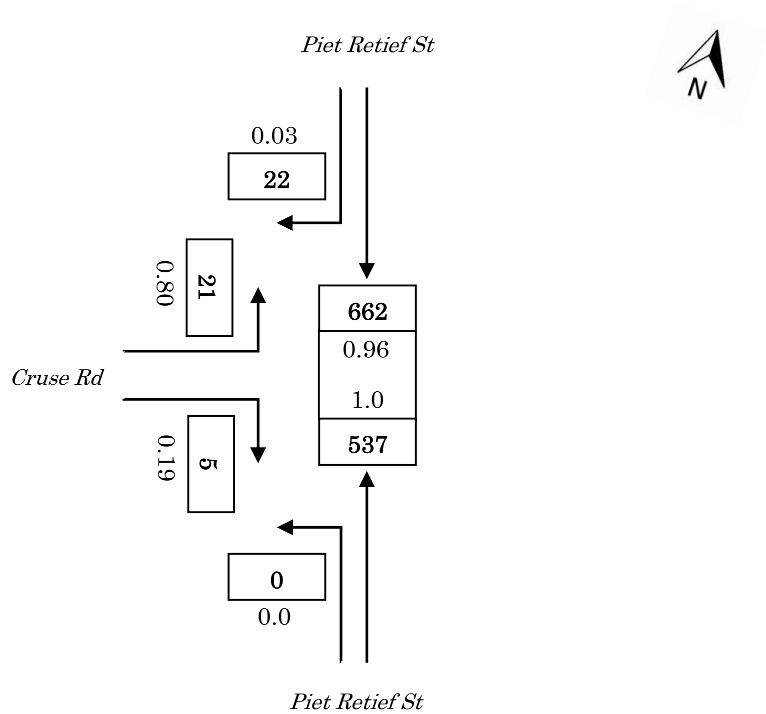
11

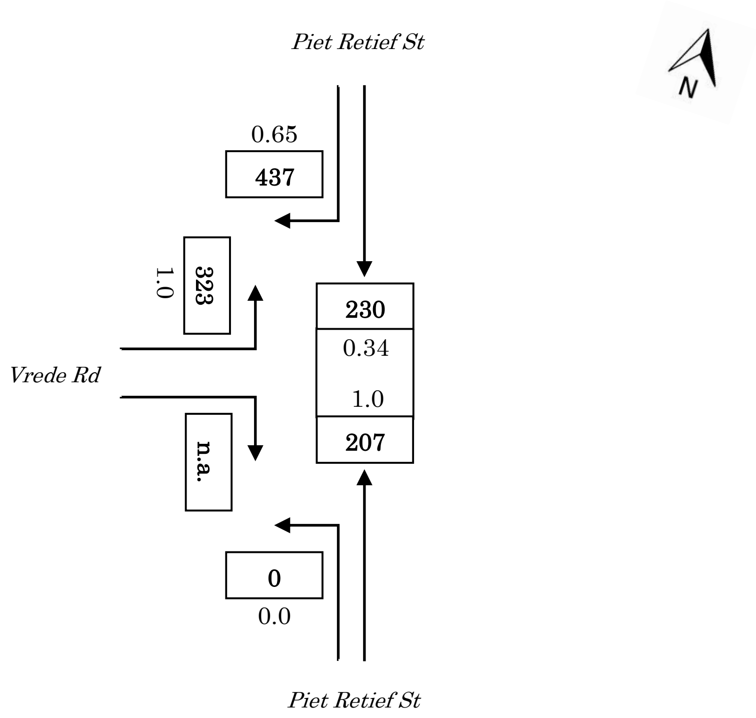
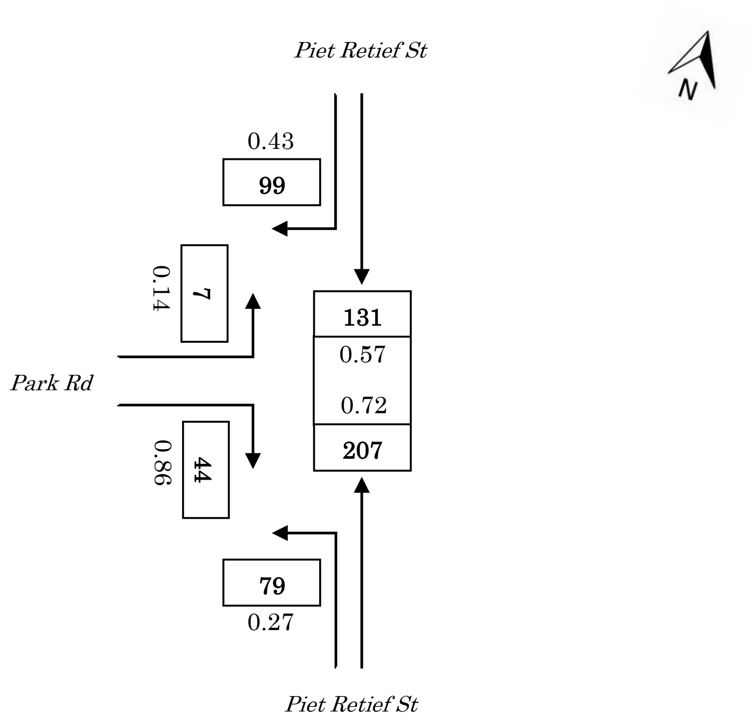

Piet Retief St
0.02
18
0.96
178
703
0.97
Ackermann Rd
0.98
603
0.03
7
10
0.01
Piet Retief St
N

12

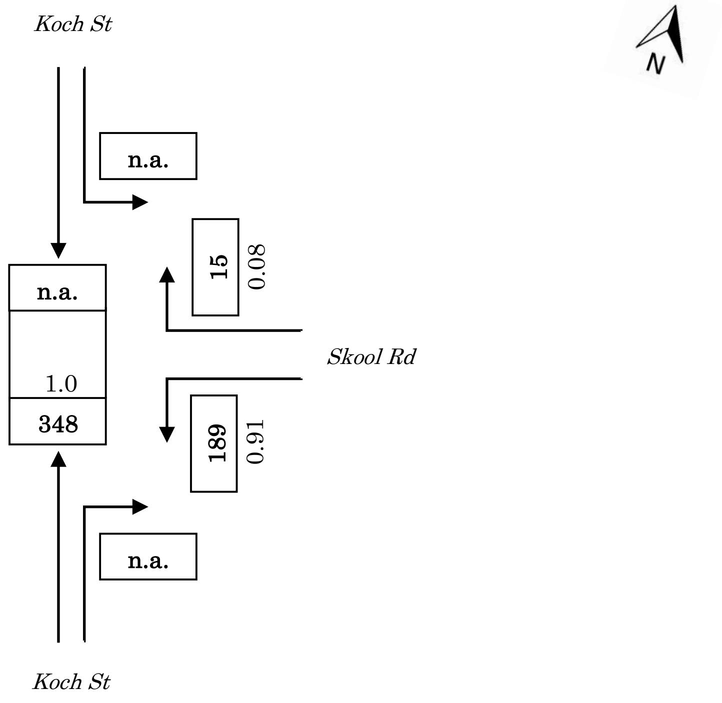

Piet Retief St
N
0.04
35
0.85
55
Jean Rd
0.14
9
675
0.95
1.0
558
0
0.0
Piet Retief St

13

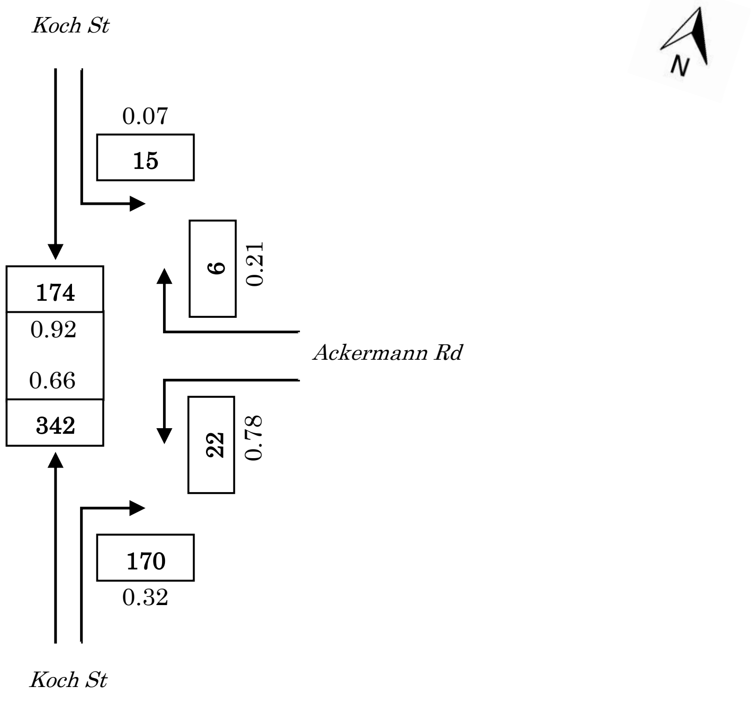

Piet Retief St
N
0.03
22
0.80
21
Cruse Rd
0.19
5
662
0.96
1.0
537
0
0.0
Piet Retief St

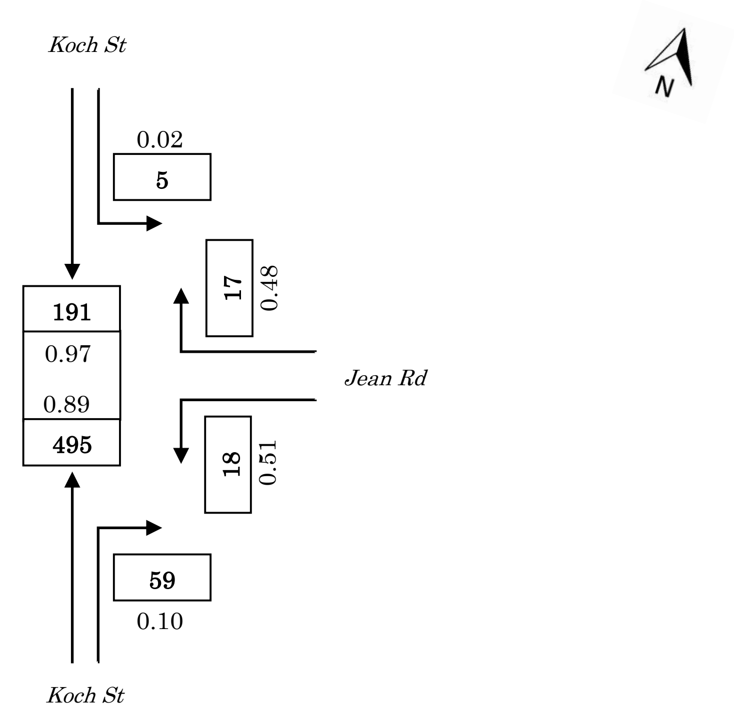
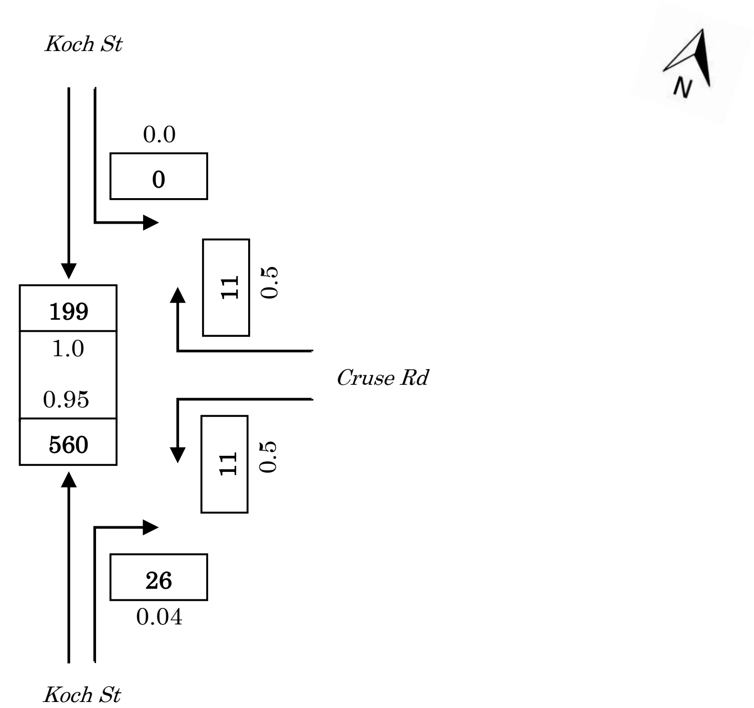
14	 Piet Retief St 0.65 437 1.0 323 230 0.34 1.0 207 Vrede Rd n.a. 0 0.0 Piet Retief St
15	 Piet Retief St 0.43 99 0.14 7 131 0.57 0.72 207 Park Rd 0.86 44 79 0.27 Piet Retief St

16


Koch St
n.a.
n.a.
15
0.08
1.0
348
Skool Rd
189
0.91
n.a.
Koch St

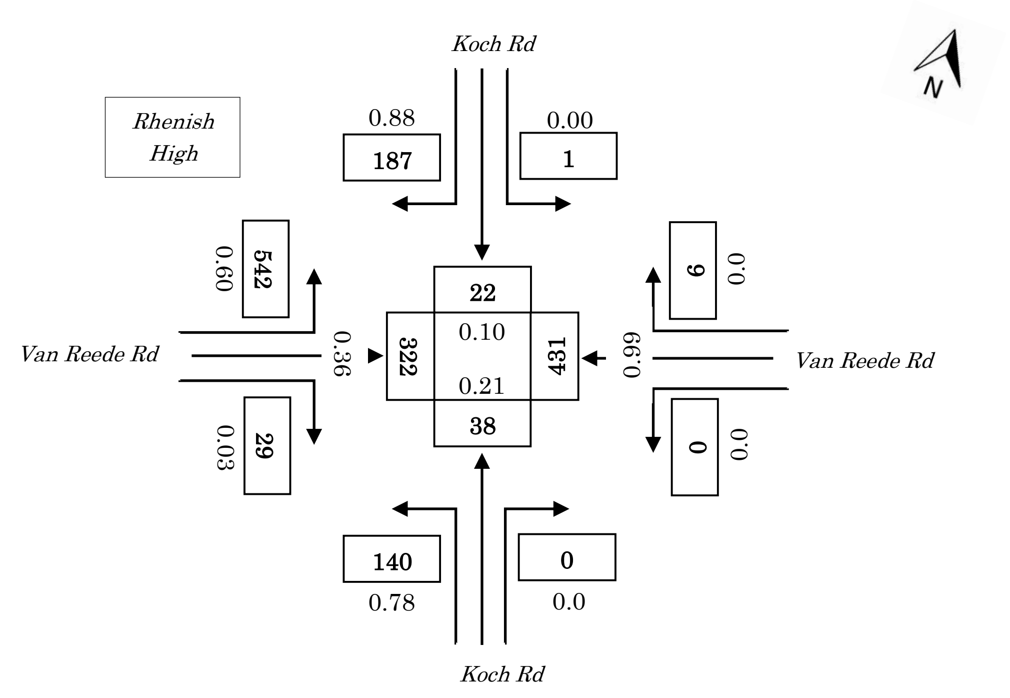
17


Koch St
0.07
15
6
0.21
174
0.92
0.66
342
Ackermann Rd
22
0.78
170
0.32
Koch St

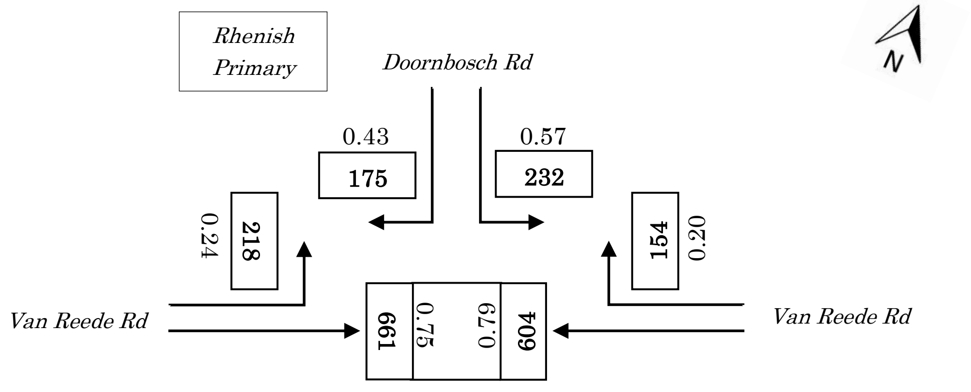
18	Koch St 0.02 5 17 0.48 191 0.97 0.89 495 Jean Rd 18 0.51 59 0.10 Koch St N
19	Koch St 0.0 0 11 0.5 199 1.0 0.95 560 Cruse Rd 11 0.5 26 0.04 Koch St N

20

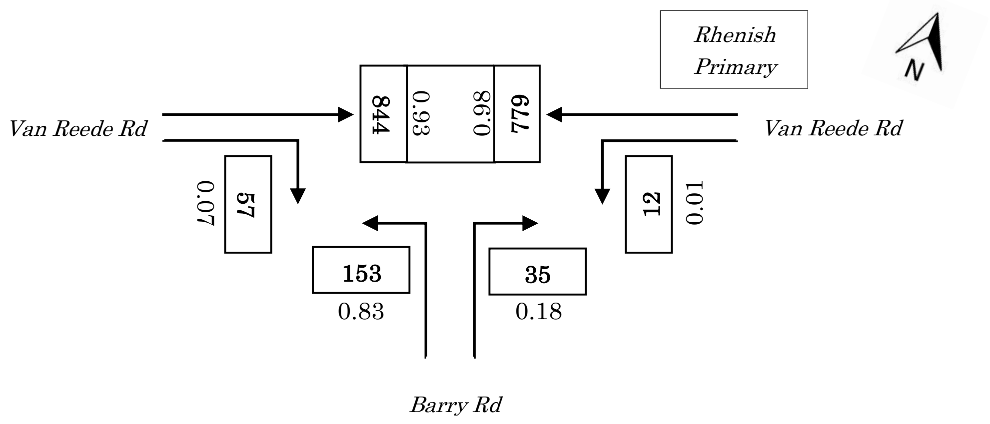
(PHF = 0.88)



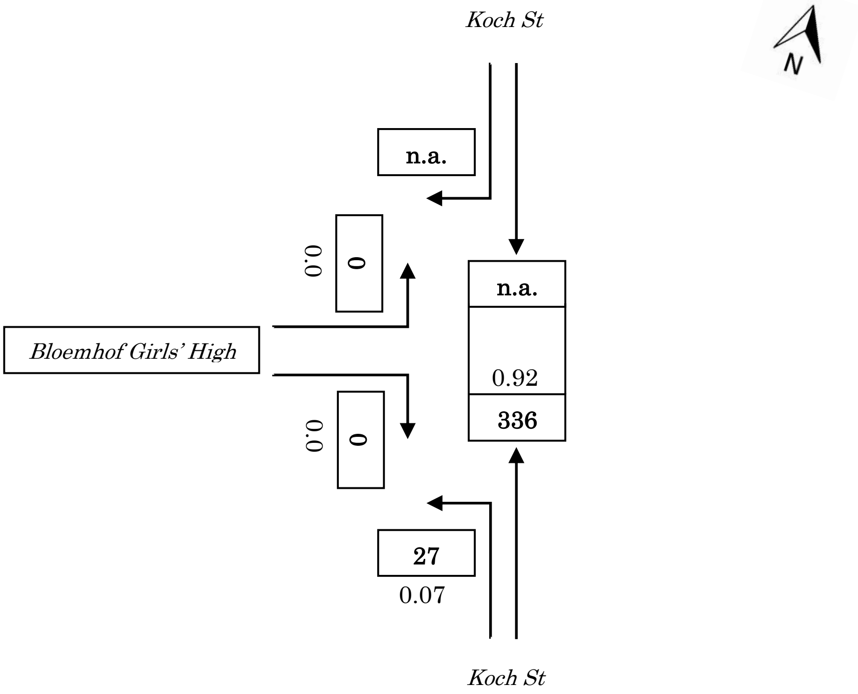
21



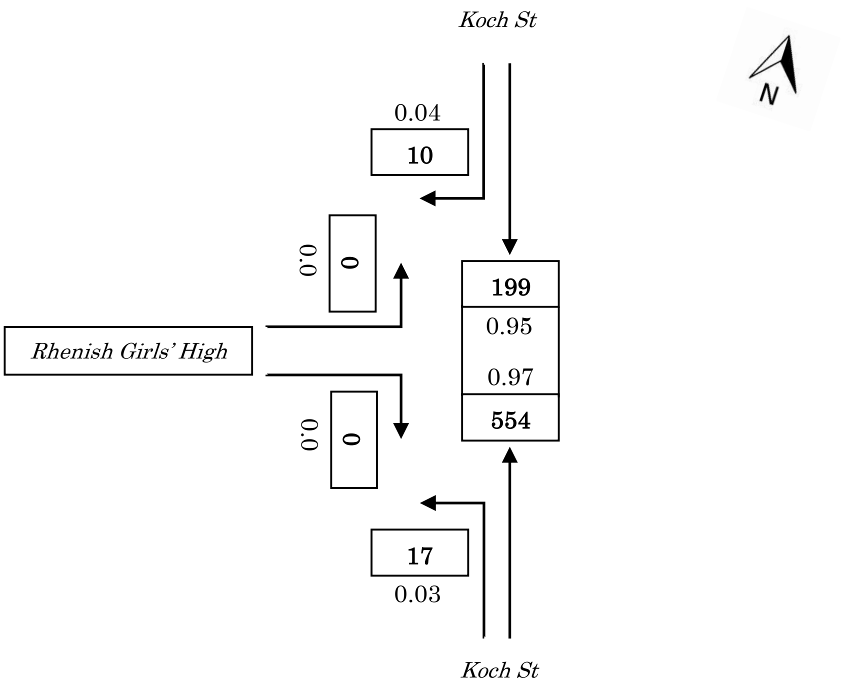
22



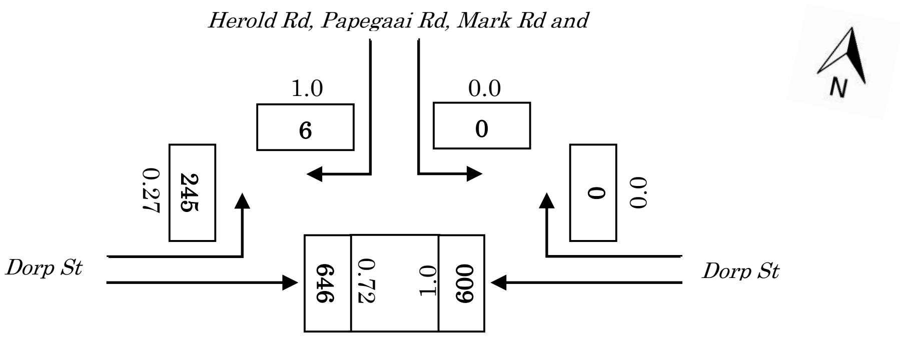
23

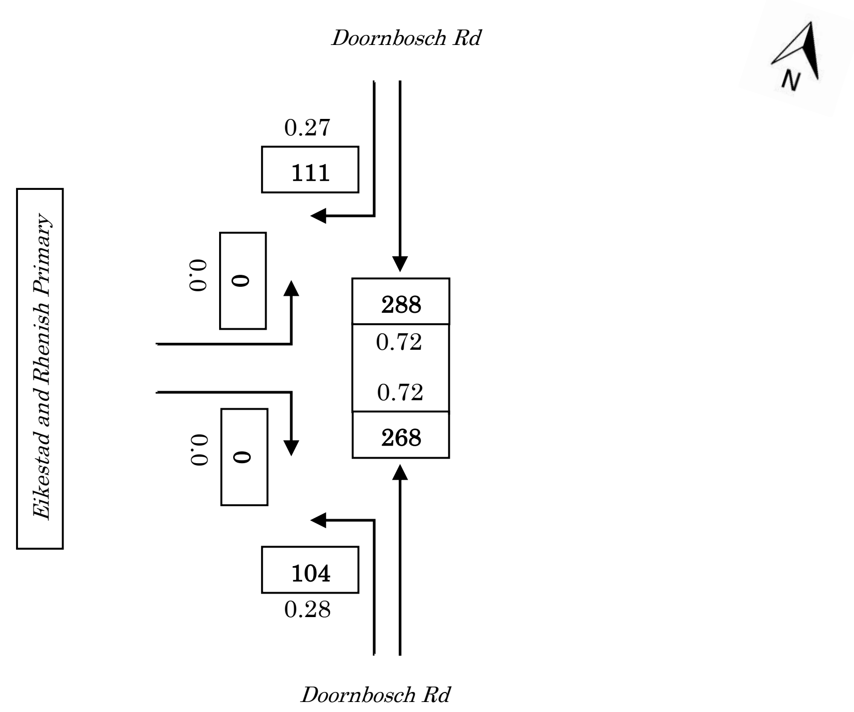

Koch St
N
n.a.
0
0.0
n.a.
Bloemhof Girls' High
0.92
336
0
0.0
27
0.07
Koch St

24


Koch St
N
0.04
10
0
0.0
199
0.95
Rhenish Girls' High
0.97
554
0
0.0
17
0.03
Koch St

25


Herold Rd, Papegaai Rd, Mark Rd and
N
1.0
6
0.0
0
245
0.27
0
0.0
Dorp St
646
0.72
1.0
600
Dorp St

26	

Doornbosch Rd
0.27
111
Eikestad and Rhenish Primary
0.0
0
288
0.72
0.72
268
0.0
0
104
0.28
Doornbosch Rd
N

E.3 PHF FOR THE MAJOR INTERSECTIONS IN THE STUDY AREA

Table E.2: PHF for the major intersections in the study area.

Intersection		Turn movement													
		4	5	6	7	8	9	10	11	12	1	2	3	Total	PHF
2	07:00 - 07:15	37	378	188	136	6	12	32	246	3	1	52	20	1111	0.96
	07:15 - 07:30	45	390	109	144	7	17	55	224	4	3	54	19	1071	
	07:30 - 07:45	59	284	138	169	29	26	22	217	10	4	41	37	1036	
	07:45 - 08:00	71	209	177	318	40	16	19	226	11	2	17	31	1137	
		212	1261	612	767	82	71	128	913	28	10	164	107		
4															
	07:00 - 07:15	11	353	16	6	2	21	33	278	42	42	11	16	831	0.88
	07:15 - 07:30	12	328	25	7	10	16	71	276	32	71	51	17	916	
	07:30 - 07:45	4	246	22	4	16	24	85	250	46	46	32	17	792	
	07:45 - 08:00	11	227	5	5	3	40	20	186	57	107	11	15	687	
		38	1154	68	22	31	101	209	990	177	266	105	65		
5															
	07:00 - 07:15	56	254	115	64	44		4	224		3	107	72	943	0.96
	07:15 - 07:30	48	239	124	151	59		5	203		4	78	70	981	
	07:30 - 07:45	64	209	117	106	56		7	217		7	85	70	938	
	07:45 - 08:00	93	237	130	58	62		11	151		4	108	41	895	
		261	939	486	379	221		27	795		18	378	253		
6															
	07:00 - 07:15	22	84	7	124	70	3				79	50	40	479	0.96
	07:15 - 07:30	54	74	5	63	142	9				65	64	31	507	
	07:30 - 07:45	45	102	7	73	110	12				70	70	18	507	
	07:45 - 08:00	41	110	13	92	105	8				64	77	17	527	
		162	370	32	352	427	32				278	261	106		
7															
	07:00 - 07:15					71		18		126		58		273	

	07:15 - 07:30					106		22		108		73		309	0.95
	07:30 - 07:45					94		40		101		74		309	
	07:45 - 08:00					104		22		101		89		316	
						375		102		436		294			
9	07:00 - 07:15		106	62	43		14	21		131	31	19	4	431	0.93
	07:15 - 07:30		114	67	101		24	17		120	62	22	6	533	
	07:30 - 07:45		147	42	113		19	7		148	60	23	5	564	
	07:45 - 08:00		180	41	47		6	14		171	75	25	4	563	
			547	212	304		63	59		570	228	89	19		
20	07:00 - 07:15	10	5			113	0	0	2	42	112	120	3	407	0.88
	07:15 - 07:30	41	17			111	2	0	7	81	165	82	3	509	
	07:30 - 07:45	62	15			111	3	1	12	67	172	67	14	524	
	07:45 - 08:00	36	4			126	1	0	3	10	131	75	11	397	
		149	41			461	6	1	24	200	580	344	31		

E.4 PROBE DATA INPUT FOR SPEED PROFILES AND CUMULATIVE TRAVEL TIME GRAPHS

Table E.3: 2015 probe input data for the speed profiles of the three potential AM peak periods and free flow.

Distance along route	Location of intersections	Speed (km/h)			
		Free-flow	06:45 to 07:45	07:00 to 08:00	07:15 to 08:15
241.16		66.97	64.76	59.15	59.62
294.62		86.50	80.03	80.17	82.00
479.86		87.43	77.20	77.45	79.39
596.61		85.67	73.86	73.36	75.23
620.42		85.76	72.93	71.84	74.08
1050.72		89.16	69.06	68.10	69.55
1183.55		91.74	60.15	60.19	62.23
1624.13		90.97	48.30	47.05	51.68
1868.92		91.85	46.27	44.80	49.43
2178.42		92.44	41.05	38.67	43.92
2245.74		93.08	41.49	37.94	37.72
2417.54		91.27	35.65	32.31	34.34
2428.61		88.11	34.37	31.07	34.08
2577.63		85.09	30.10	28.49	32.61
3006.96	R44 / Webersvallei Rd	68.85	25.62	26.00	27.68
3315.92		77.49	56.10	47.07	38.95
3449.84		81.58	39.77	31.94	31.22
3664.35		78.73	29.00	24.88	21.06
3690.84	R44 / Tegno Rd	77.89	25.00	20.26	22.27
4604.90	R44 / Blaauwklippen Rd	79.45	28.37	32.03	37.30
5102.96	R44 / Paradyskloof Rd	83.60	55.05	57.23	61.07
5311.21		80.26	50.35	51.80	59.06
5320.39		73.29	33.92	33.42	42.86
5406.53	R44 / Trumali Rd	61.07	28.23	30.40	32.90
5579.84		67.70	51.74	54.31	55.81
5678.68		76.47	39.37	42.67	48.41
5784.14		78.38	31.44	34.51	40.85
5938.89		79.51	14.00	16.05	20.26
6024.02		78.27	9.03	8.63	12.04
6069.95		76.63	8.67	8.02	10.22
6361.15	R44 / Van Reede Rd	54.39	7.02	6.64	8.07

Table E.4: 2015 probe input data for the cumulative travel time graphs of the three potential AM peak periods and free flow.

Distance along route	Location of intersections	Cumulative travel time (s)			
		Free-flow	06:45 to 07:45	07:00 to 08:00	07:15 to 08:15
241.16		12.96	13.41	14.68	14.56
294.62		15.19	15.81	17.08	16.91
479.86		22.82	24.45	25.69	25.31
596.61		27.72	30.14	31.42	30.89
620.42		28.72	31.32	32.61	32.05
1050.72		46.10	53.75	55.36	54.33
1183.55		51.31	61.70	63.30	62.01
1624.13		68.74	94.53	97.01	92.70
1868.92		78.34	113.58	116.69	110.53
2178.42		90.39	140.72	145.50	135.89
2245.74		93.00	146.56	151.88	142.32
2417.54		99.77	163.91	171.03	160.33
2428.61		100.22	165.07	172.31	161.50
2577.63		106.53	182.89	191.14	177.95
3006.96	R44 / Webersvallei Rd	128.98	243.22	250.60	233.79
3315.92		143.33	263.05	274.23	262.34
3449.84		149.24	275.17	289.32	277.79
3664.35		159.05	301.80	320.36	314.45
3690.84	R44 / Tegno Rd	160.27	305.61	325.07	318.74
4604.90	R44 / Blaauwklippen Rd	201.69	421.58	427.81	406.96
5102.96	R44 / Paradyskloof Rd	223.14	454.15	459.14	436.33
5311.21		232.48	469.04	473.61	449.02
5320.39		232.93	470.02	474.60	449.79
5406.53	R44 / Trumali Rd	238.01	481.00	484.80	459.22
5579.84		247.23	493.06	496.29	470.39
5678.68		251.88	502.10	504.63	477.75
5784.14		256.72	514.17	515.63	487.04
5938.89		263.73	553.96	550.34	514.53
6024.02		267.64	587.92	585.87	539.99
6069.95		269.80	606.99	606.49	556.16
6361.15	R44 / Van Reede Rd	289.08	756.28	764.42	686.00

E.5 BASE MODEL O-D MATRIX RESULTS

Table E.5: The matrix of trip-production proportions per origin.

	1	2	3	4	5a	5b	5	6	7	8a	8b	8c	8d	8	9	10	11	12	13	14	15	16	17	18	Total
1	0.012	0.097	0.015	0.017	0.030	0.066	0.096	0.081	0.279	0.000	0.010	0.020	0.010	0.040	0.066	0.044	0.002	0.017	0.019	0.001	0.125	0.007	0.018	0.055	0.990
2	0.350	0.000	0.001	0.001	0.004	0.136	0.140	0.012	0.017	0.000	0.001	0.001	0.001	0.002	0.024	0.004	0.000	0.016	0.038	0.001	0.257	0.011	0.037	0.032	0.944
3	0.477	0.018	0.000	0.012	0.022	0.016	0.037	0.057	0.201	0.000	0.007	0.014	0.007	0.029	0.038	0.031	0.002	0.004	0.005	0.000	0.029	0.003	0.004	0.043	0.990
4	0.102	0.004	0.001	0.000	0.242	0.003	0.246	0.097	0.349	0.000	0.012	0.025	0.012	0.050	0.057	0.053	0.003	0.001	0.003	0.001	0.006	0.003	0.001	0.009	0.985
5a	0.087	0.003	0.000	0.208		0.000	0.000	0.105	0.378	0.000	0.013	0.027	0.013	0.054	0.061	0.057	0.003	0.000	0.002	0.001	0.004	0.003	0.001	0.008	0.974
5b	0.324	0.038	0.001	0.001	0.000		0.000	0.004	0.016	0.000	0.000	0.000	0.000	0.000	0.061	0.005	0.000	0.048	0.052	0.001	0.355	0.016	0.006	0.029	0.958
5	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.229	0.009	0.001	0.050	0.060	0.013	0.073	0.000	0.032	0.000	0.040	0.081	0.040	0.160	0.185	0.172	0.010	0.002	0.008	0.002	0.024	0.008	0.001	0.021	0.987
7	0.531	0.020	0.003	0.130	0.148	0.018	0.166	0.004		0.000	0.003	0.005	0.003	0.010	0.016	0.010	0.001	0.005	0.005	0.000	0.033	0.002	0.005	0.048	0.988
8a	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8b	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8c	0.346	0.013	0.002	0.082	0.097	0.012	0.108	0.368	0.000	0.000	0.000		0.000	0.000	0.004	0.000	0.000	0.003	0.003	0.000	0.021	0.001	0.003	0.031	0.986
8d	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.346	0.013	0.002	0.082	0.097	0.012	0.108	0.368	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.003	0.003	0.000	0.021	0.001	0.003	0.031	0.986
9	0.238	0.016	0.001	0.035	0.041	0.037	0.078	0.158	0.003	0.000	0.000	0.000	0.000	0.000	0.032	0.191	0.049	0.004	0.029	0.011	0.062	0.039	0.002	0.021	0.967
10	0.294	0.020	0.001	0.043	0.051	0.045	0.096	0.195	0.003	0.000	0.000	0.000	0.000	0.000	0.041	0.000	0.060	0.004	0.036	0.013	0.084	0.049	0.002	0.027	0.967
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.291	0.033	0.001	0.001	0.001	0.100	0.102	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.033	0.003	0.000	0.000	0.089	0.034	0.198	0.124	0.006	0.031	0.950
13	0.286	0.032	0.001	0.003	0.003	0.096	0.100	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.074	0.006	0.000	0.058	0.000	0.033	0.212	0.119	0.006	0.026	0.968
14	0.046	0.002	0.000	0.011	0.013	0.000	0.013	0.048	0.000	0.000	0.000	0.000	0.000	0.000	0.292	0.025	0.004	0.230	0.265		0.000	0.010	0.000	0.000	0.946
15	0.149	0.017	0.000	0.000	0.001	0.051	0.051	0.017	0.007	0.000	0.000	0.001	0.000	0.001	0.093	0.009	0.000	0.073	0.079	0.410		0.027	0.003	0.013	0.953
16	0.130	0.015	0.000	0.008	0.010	0.044	0.054	0.037	0.002	0.000	0.000	0.000	0.000	0.001	0.215	0.019	0.000	0.175	0.190	0.012	0.057	0.000	0.003	0.012	0.931
17	0.624	0.072	0.002	0.002	0.003	0.046	0.049	0.011	0.030	0.000	0.001	0.002	0.001	0.004	0.020	0.006	0.000	0.012	0.012	0.000	0.085	0.004	0.000	0.056	0.990
18	0.319	0.070	0.011	0.012	0.022	0.048	0.070	0.060	0.203	0.000	0.007	0.014	0.007	0.029	0.048	0.032	0.002	0.012	0.014	0.001	0.086	0.005	0.013	0.001	0.987

Table E.6: The unbalanced, incomplete original O-D matrix.

UNBALANCED ORIGINAL O-D MATRIX 7-8AM				DESTINATIONS																		
				1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	
				ATTRACTIONS																		
				1689	327	39	258	771	482	957	245	680	396	63	288	350	*363*	*790*	175	69	263	**8205**
ORIGINS	**1**	PRODUCTIONS	2182	27	211	32	37	210	177	609	86	144	96	5	36	42	2	272	16	38	119	2161
	2		281	98	0	0	0	39	3	5	1	7	1	0	5	11	0	72	3	10	9	265
	3		38	18	1	0	0	1	2	8	1	1	1	0	0	0	0	1	0	0	2	38
	4		434	44	2	0	0	107	42	152	21	25	23	1	0	1	0	3	1	0	4	426
	5		556	145	16	0	31	0	17	63	8	34	11	0	20	22	1	145	7	3	13	534
	6		649	149	6	1	33	47	0	21	104	120	112	6	2	5	1	16	5	0	13	635
	7		822	437	16	2	107	136	3	0	9	13	8	0	4	4	0	27	2	4	39	812
	8		6	2	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	6
	9		538	128	9	1	19	42	85	1	0	17	103	26	2	15	6	33	21	1	12	494
	10		375	110	7	0	16	36	73	1	0	15	0	22	2	13	5	32	18	1	10	340
	11		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12		253	74	8	0	0	26	1	0	0	8	1	0	0	23	9	50	31	1	8	240
	13		367	105	12	0	1	37	5	0	0	27	2	0	21	0	12	78	44	2	9	355
	14		336	15	1	0	4	4	16	0	0	98	8	1	77	89	0	0	3	0	0	316
	15		763	114	13	0	0	39	13	6	1	71	7	0	56	60	313	0	21	2	10	727
	16		286	37	4	0	2	15	11	1	0	62	6	0	50	54	3	16	0	1	3	266
	17		188	117	14	0	0	9	2	6	1	4	1	0	2	2	0	16	1	0	11	186
	18		55	18	4	1	1	4	3	11	2	3	2	0	1	1	0	5	0	1	0	54
			8129	1637	323	39	253	754	457	882	234	648	382	64	277	343	353	766	174	66	263	

E.6 PATHS PER O-D PAIR IN THE VISUM MODEL AFTER EQUILIBRIUM ASSIGNMENT

Table E.7: The paths per O-D pair in the Visum base model after equilibrium assignment.

Origin Zone No.	Destination Zone No.	Path in terms of streets traversed (in order)						
1	2	R44	Van Reede					
	3	R44	turn-off into Zone 3					
	4	R44	Saffraan					
	5	R44	Van Reede	Doornbosch				
	6	R44	Dorp					
	7	R44						
	8	R44	Dorp					
	8	R44	Dorp					
	8	R44	Dorp					
	8	R44	Dorp					
	9	R44	Dorp	Mill				
	10	R44	Dorp					
	11	R44	Dorp	Piet Retief	Stelkor Parking			
	12	R44	Van Reede	Koch	Vrede	Piet Retief	Noordwal-Wes	
	13	R44	Van Reede	Koch	Vrede	Piet Retief	Suidwal	
	14	R44	Van Reede	Koch	Vrede	Piet Retief	Skool	Koch
	15	R44	Van Reede	Koch				
	16	R44	Van Reede	Koch	Park			
	17	R44	Van Reede	Barry				
	18	R44	Trumali					
2	1	Van Reede	R44					
	5	Van Reede	Doornbosch					
	6	Van Reede	R44	Dorp				
	7	Van Reede	R44					

	8	Van Reede	R44	Dorp				
	8	Van Reede	R44	Dorp				
	8	Van Reede	R44	Dorp				
	8	Van Reede	R44	Dorp				
	9	Van Reede	R44	Dorp	Mill			
	10	Van Reede	R44	Dorp				
	12	Van Reede	Koch	Vrede	Piet Retief	Noordwal-Wes		
	13	Van Reede	Koch	Vrede	Piet Retief	Suidwal		
	14	Van Reede	Koch	Vrede	Piet Retief	Skool	Koch	
	15	Van Reede	Koch					
	16	Van Reede	Koch	Park				
	17	Van Reede	Barry					
	18	Van Reede	R44	Trumali				
3	1	turn-off from Zone 3	R44					
	2	turn-off from Zone 3	R44	Van Reede				
	5	turn-off from Zone 3	R44	Van Reede	Doornbosch			
	6	turn-off from Zone 3	R44	Dorp				
	7	turn-off from Zone 3	R44					
	8	turn-off from Zone 3	R44	Dorp				
	8	turn-off from Zone 3	R44	Dorp				
	8	turn-off from Zone 3	R44	Dorp				
	8	turn-off from Zone 3	R44	Dorp				
	9	turn-off from Zone 3	R44	Dorp	Mill			
	10	turn-off from Zone 3	R44	Dorp				
	15	turn-off from Zone 3	R44	Van Reede	Koch			
	18	turn-off from Zone 3	R44	Trumali				
4	1	Saffraan	R44					
	2	Saffraan	R44	Van Reede				
	5	Saffraan	Doornbosch					
	6	Saffraan	R44	Dorp				
	7	Saffraan	R44					

	8	Saffraan	R44	Dorp				
	8	Saffraan	R44	Dorp				
	8	Saffraan	R44	Dorp				
	8	Saffraan	R44	Dorp				
	9	Saffraan	R44	Dorp	Mill			
	10	Saffraan	R44	Dorp				
	11	Saffraan	R44	Dorp	Piet Retief	Stelkor Parking		
	12	Saffraan	R44	Dorp	Piet Retief	Noordwal-Wes		
	13	Saffraan	R44	Dorp	Piet Retief	Suidwal		
	15	Saffraan	R44	Van Reede	Koch			
	16	Saffraan	R44	Van Reede	Koch	Park		
	17	Saffraan	R44	Van Reede	Barry			
	18	Saffraan	R44	Trumali				
5	1	Doornbosch	Van Reede	R44				
	2	Doornbosch	Van Reede					
	3	Doornbosch	R44	turn-off into Zone 3				
	4	Doornbosch	Saffraan					
	6	Doornbosch	R44	Dorp				
	7	Doornbosch	R44					
	8	Doornbosch	R44	Dorp				
	8	Doornbosch	R44	Dorp				
	8	Doornbosch	R44	Dorp				
	8	Doornbosch	R44	Dorp				
	9	Doornbosch	R44	Dorp	Mill			
	10	Doornbosch	R44	Dorp				
	11	Doornbosch	R44	Dorp	Piet Retief	Stelkor Parking		
	12	Doornbosch	Van Reede	Koch	Vrede	Piet Retief	Noordwal-Wes	
	13	Doornbosch	Van Reede	Koch	Vrede	Piet Retief	Suidwal	
	14	Doornbosch	Van Reede	Koch	Vrede	Piet Retief	Skool	Koch
	15	Doornbosch	Van Reede	Koch				
	16	Doornbosch	Van Reede	Koch	Park			

	17	Doornbosch	Van Reede	Barry				
	18	Doornbosch	Van Reede	R44	Trumali			
6	1	Dorp	R44					
	2	Dorp	R44	Van Reede				
	3	Dorp	R44	turn-off into Zone 3				
	4	Dorp	R44	Saffraan				
	5	Dorp	R44	Doornbosch				
	7	Dorp	R44					
	8	Dorp						
	8	Dorp						
	8	Dorp						
	8	Dorp						
	9	Dorp	Mill					
	10	Dorp						
	11	Dorp	Piet Retief	Stelkor Parking				
	12	Dorp	Piet Retief	Noordwal-Wes				
	13	Dorp	Piet Retief	Suidwal				
	14	Dorp	Piet Retief	Skool	Koch			
	15	Dorp	Piet Retief	Skool	Koch			
	16	Dorp	Piet Retief					
	17	Dorp	R44	Van Reede	Barry			
	18	Dorp	R44	Trumali				
7	1	R44						
	2	R44	Van Reede					
	3	R44	turn-off into Zone 3					
	4	R44	Saffraan					
	5	R44	Doornbosch					
	6	R44	U-turn	R44	Dorp			
	8	R44	Dorp					
	8	R44	Dorp					
	8	R44	Dorp					

	8	R44	Dorp					
	9	R44	Dorp	Mill				
	10	R44	Dorp					
	12	R44	Dorp	Piet Retief	Noordwal-Wes			
	13	R44	Dorp	Piet Retief	Suidwal			
	14	R44	Dorp	Piet Retief	Skool	Koch		
	15	R44	Dorp	Piet Retief	Skool	Koch		
	16	R44	Dorp	Piet Retief				
	17	R44	Van Reede	Barry				
	18	R44	Trumali					
8	1	Dorp	R44					
	1	Dorp	R44					
	1	Dorp	R44					
	4	Dorp	R44	Saffraan				
	4	Dorp	R44	Saffraan				
	4	Dorp	R44	Saffraan				
	5	Dorp	R44	Doornbosch				
	5	Dorp	R44	Doornbosch				
	5	Dorp	R44	Doornbosch				
	6	Dorp						
	6	Dorp						
	6	Dorp						
9	1	Bird	Dorp	R44				
	2	Bird	Dorp	R44	Van Reede			
	3	Bird	Dorp	R44	turn-off into Zone 3			
	4	Bird	Dorp	R44	Saffraan			
	5	Bird	Dorp	R44	Doornbosch			
	6	Bird	Dorp					
	7	Bird	Dorp	R44	U-turn	R44		
	10	Bird	Dorp					
	11	Bird	Dorp	Piet Retief	Stelkor Parking			

	12	Bird	Dorp	Piet Retief	Noordwal-Wes			
	13	Bird	Dorp	Piet Retief	Suidwal			
	14	Bird	Dorp	Piet Retief	Skool	Koch		
	15	Bird	Dorp	Piet Retief	Skool	Koch		
	16	Bird	Dorp	Piet Retief				
	17	Bird	Dorp	Piet Retief	Vrede	Koch	Van Reede	Barry
	18	Bird	Dorp	R44	Trumali			
10	1	Dorp	R44					
	2	Dorp	R44	Van Reede				
	3	Dorp	R44	turn-off into Zone 3				
	4	Dorp	R44	Saffraan				
	5	Dorp	R44	Doornbosch				
	6	Dorp						
	7	Dorp	R44	U-turn	R44			
	9	Dorp	Mill					
	11	Dorp	Piet Retief	Stelkor Parking				
	12	Dorp	Piet Retief	Noordwal-Wes				
	13	Dorp	Piet Retief	Suidwal				
	14	Dorp	Piet Retief	Skool	Koch			
	15	Dorp	Piet Retief	Skool	Koch			
	16	Dorp	Piet Retief					
	17	Dorp	Piet Retief	Vrede	Koch	Van Reede	Barry	
	18	Dorp	R44	Trumali				
12	1	Noordwal-Wes	Piet Retief	Vrede	Koch	Van Reede	R44	
	2	Noordwal-Wes	Piet Retief	Vrede	Koch	Van Reede		
	5	Noordwal-Wes	Piet Retief	Vrede	Koch	Van Reede	Doornbosch	
	6	Noordwal-Wes	Piet Retief	Dorp				
	9	Noordwal-Wes	Piet Retief	Mill				
	10	Noordwal-Wes	Piet Retief	Dorp				
	13	Noordwal-Wes	Piet Retief	Suidwal				
	14	Noordwal-Wes	Piet Retief	Skool	Koch			

	15	Noordwal-Wes	Piet Retief	Skool	Koch			
	16	Noordwal-Wes	Piet Retief					
	17	Noordwal-Wes	Piet Retief	Vrede	Koch	Van Reede	Barry	
	18	Noordwal-Wes	Piet Retief	Vrede	Koch	Van Reede	R44	Trumali
13	1	Suidwal	Piet Retief	Vrede	Koch	Van Reede	R44	
	2	Suidwal	Piet Retief	Vrede	Koch	Van Reede		
	4	Suidwal	Piet Retief	Dorp	R44	Saffraan		
	5	Suidwal	Piet Retief	Vrede	Koch	Van Reede	Doornbosch	
	6	Suidwal	Piet Retief	Dorp				
	9	Suidwal	Piet Retief	Mill				
	10	Suidwal	Piet Retief	Dorp				
	12	Suidwal	Piet Retief	Noordwal-Wes				
	14	Suidwal	Piet Retief	Skool	Koch			
	15	Suidwal	Piet Retief	Skool	Koch			
	16	Suidwal	Piet Retief					
	17	Suidwal	Piet Retief	Vrede	Koch	Van Reede	Barry	
	18	Suidwal	Piet Retief	Vrede	Koch	Van Reede	R44	Trumali
14	1	Koch	Van Reede	R44				
	2	Koch	Van Reede					
	4	Koch	Van Reede	R44	Saffraan			
	5	Koch	Van Reede	Doornbosch				
	6	Koch	Suidwal	Piet Retief	Dorp			
	9	Koch	Suidwal	Piet Retief	Mill			
	10	Koch	Suidwal	Piet Retief	Dorp			
	11	Koch	Van Reede	R44	Dorp	Piet Retief	Stelkor Parking	
	12	Koch	Suidwal	Piet Retief	Noordwal-Wes			
	13	Koch	Suidwal					
	16	Koch	Ackermann	Piet Retief				
15	1	Koch	Van Reede	R44				
	2	Koch	Van Reede					
	4	Koch	Van Reede	R44	Saffraan			

	5	Koch	Van Reede	Doornbosch				
	6	Koch	Jean	Piet Retief	Dorp			
	7	Koch	Van Reede	R44				
	8	Koch	Jean	Piet Retief	Dorp			
	8	Koch	Jean	Piet Retief	Dorp			
	8	Koch	Jean	Piet Retief	Dorp			
	8	Koch	Jean	Piet Retief	Dorp			
	9	Koch	Jean	Piet Retief	Mill			
	10	Koch	Jean	Piet Retief	Dorp			
	12	Koch	Jean	Piet Retief	Noordwal-Wes			
	13	Koch	Jean	Piet Retief	Suidwal			
	14	Koch						
	16	Koch	Cruse	Piet Retief				
	17	Koch	Van Reede	Barry				
	18	Koch	Van Reede	R44	Trumali			
16	1	Park	Koch	Van Reede	R44			
	2	Park	Koch	Van Reede				
	4	Park	Koch	Van Reede	R44	Saffraan		
	5	Park	Koch	Van Reede	Doornbosch			
	6	Piet Retief	Dorp					
	7	Park	Koch	Van Reede	R44			
	9	Piet Retief	Mill					
	10	Piet Retief	Dorp					
	12	Piet Retief	Noordwal-Wes					
	13	Piet Retief	Suidwal					
	14	Piet Retief	Skool	Koch				
	15	Piet Retief	Jean	Koch				
	17	Park	Koch	Van Reede	Barry			
	18	Park	Koch	Van Reede	R44	Trumali		
17	1	Barry	Van Reede	R44				
	2	Barry	Van Reede					

	5	Barry	Van Reede	Doornbosch				
	6	Barry	Van Reede	R44	Dorp			
	7	Barry	Van Reede	R44				
	8	Barry	Van Reede	R44	Dorp			
	8	Barry	Van Reede	R44	Dorp			
	8	Barry	Van Reede	R44	Dorp			
	8	Barry	Van Reede	R44	Dorp			
	9	Barry	Van Reede	Koch	Vrede	Piet Retief	Mill	
	10	Barry	Van Reede	Koch	Vrede	Piet Retief	Dorp	
	12	Barry	Van Reede	Koch	Vrede	Piet Retief	Noordwal-Wes	
	13	Barry	Van Reede	Koch	Vrede	Piet Retief	Suidwal	
	15	Barry	Van Reede	Koch				
	16	Barry	Van Reede	Koch	Park			
	18	Barry	Van Reede	R44	Trumali			
18	1	Trumali	R44					
	2	Trumali	R44	Van Reede				
	3	Trumali	R44	turn-off into Zone 3				
	4	Trumali	R44	Saffraan				
	5	Trumali	R44	Van Reede	Doornbosch			
	6	Trumali	R44	Dorp				
	7	Trumali	R44					
	8	Trumali	R44	Dorp				
	8	Trumali	R44	Dorp				
	8	Trumali	R44	Dorp				
	8	Trumali	R44	Dorp				
	9	Trumali	R44	Dorp	Mill			
	10	Trumali	R44	Dorp				
	13	Trumali	R44	Van Reede	Koch	Piet Retief	Suidwal	
	15	Trumali	R44	Van Reede	Koch			
	17	Trumali	R44	Van Reede	Barry			

E.7 BASE-MODEL GEH RESULTS

Table E.8: GEH results of the base model for every turn and main turn in the network.

	From node no.	Via node no.	To node no.	Turn type	Modelled volume	Observed volume	GEH
Turns	212	6	294	2	2113	2106	0.16
	7	8	10	1	13	7	1.85
	7	8	318	3	0	178	18.87
	8	7	9	3	0	22	6.63
	8	7	25	1	0	6	3.46
	9	10	8	3	76	55	2.65
	9	10	12	1	0	9	4.24
	10	9	7	1	0	17	5.83
	10	9	319	3	15	18	0.72
	11	12	10	3	0	21	6.48
	11	12	14	1	8	5	1.02
	12	11	13	3	0	11	4.69
	12	11	319	1	0	11	4.69
	13	14	12	3	347	323	1.32
	14	13	11	1	0	6	3.46
	14	13	115	3	443	431	0.58
	26	25	7	3	142	189	3.65
	26	25	320	1	20	15	1.21
	34	220	21	2	280	284	0.23
	220	34	303	1	16	15	0.33
	220	34	304	3	236	238	0.12
	21	220	34	2	252	253	0.04
	220	21	215	2	280	284	0.23
	215	21	220	2	252	253	0.04
	28	37	309	3	0	10	4.47
	17	42	307	3	150	153	0.28
	17	42	308	1	37	35	0.25
	240	84	22	3	101	102	0.06
	240	84	315	1	443	436	0.34
	87	116	92	2	410	407	0.14
	92	116	87	2	372	372	0.01
	116	92	306	3	245	232	0.83
	116	92	308	1	165	175	0.77
	204	205	297	2	1817	1821	0.08
	206	26	25	1	152	172	1.61
	206	26	318	2	684	721	1.41
	8	10	9	1	0	35	8.37
	8	10	12	2	696	675	0.82
	10	8	7	3	0	10	4.47
	10	8	318	2	666	603	2.51
	10	12	11	1	0	22	6.63
	10	12	14	2	696	662	1.32
	12	10	8	2	590	558	1.33
	12	10	9	3	15	0	5.49

12	14	13	1	443	437	0.30
12	14	316	2	261	230	1.97
14	12	10	2	605	557	1.99
7	25	320	2	397	348	2.54
25	7	8	3	13	15	0.58
25	7	9	2	214	174	2.89
7	9	10	3	0	5	3.16
7	9	319	2	214	191	1.63
9	7	8	1	0	170	18.44
9	7	25	2	397	348	2.54
11	13	14	3	0	1	1.41
11	13	115	2	191	209	1.25
13	11	12	1	0	26	7.21
13	11	319	2	547	560	0.53
13	115	91	2	635	640	0.22
115	13	11	2	547	580	1.37
115	13	14	1	347	322	1.38
91	115	13	2	895	902	0.25
115	91	15	2	0	22	6.63
115	91	306	1	635	618	0.66
15	91	115	2	0	38	8.72
15	91	306	3	158	140	1.47
91	15	316	3	28	29	0.24
218	219	200	3	160	167	0.57
216	218	303	2	454	458	0.21
218	216	244	2	368	370	0.12
218	216	315	1	32	32	0.04
4	214	1	2	376	375	0.07
1	214	4	2	396	396	0.02
214	1	22	2	376	375	0.07
1	22	84	2	376	375	0.07
22	1	214	2	396	396	0.02
22	84	315	2	376	375	0.07
84	22	1	2	396	396	0.02
216	219	200	2	445	591	6.41
219	216	218	1	110	106	0.35
219	216	244	3	279	278	0.05
219	216	315	2	262	262	0.03
200	219	216	2	651	646	0.19
219	200	121	2	605	594	0.44
121	200	219	2	651	646	0.19
200	121	79	2	604	594	0.39
79	121	200	2	651	646	0.19
121	79	85	2	602	594	0.34
79	85	234	2	602	600	0.09
85	79	121	2	719	707	0.47
85	234	237	2	602	600	0.10
234	85	79	2	788	830	1.48
237	234	85	2	856	891	1.17
6	294	37	2	2113	2106	0.16
297	293	298	2	1817	1821	0.08

205	297	293	2	1817	1821	0.08
34	303	218	2	559	569	0.41
303	34	220	3	4	4	0.15
303	34	304	2	387	391	0.22
218	303	34	2	391	395	0.20
218	303	321	3	63	63	0.05
303	218	216	2	399	402	0.13
303	218	219	3	160	167	0.57
34	304	222	2	623	629	0.25
304	34	220	1	276	284	0.49
304	34	303	2	543	554	0.48
222	304	34	2	819	838	0.67
89	310	117	2	1068	1067	0.03
89	310	309	1	17	30	2.80
89	310	317	3	6	4	0.75
310	117	204	2	1094	1104	0.31
37	309	301	2	1331	1290	1.14
37	309	310	1	46	72	3.43
42	307	204	2	929	920	0.31
307	42	17	1	55	57	0.24
307	42	308	2	848	844	0.13
204	307	42	2	903	901	0.06
42	308	92	2	884	879	0.18
308	42	17	3	12	12	0.09
308	42	307	2	780	779	0.03
92	308	42	2	792	791	0.04
308	92	116	3	207	218	0.78
308	92	306	2	678	661	0.64
91	306	92	2	792	758	1.24
306	91	15	1	28	29	0.24
306	91	115	3	895	864	1.03
92	306	91	2	922	893	0.98
306	92	116	1	165	154	0.90
306	92	308	2	627	604	0.93
237	312	323	2	1437	1427	0.27
301	311	302	2	1687	1686	0.03
84	315	216	2	819	811	0.29
315	84	22	2	294	294	0.01
216	315	84	2	294	294	0.01
315	216	218	3	344	352	0.43
315	216	219	2	445	427	0.87
315	216	244	1	30	32	0.31
15	316	14	3	0	7	3.74
316	15	91	1	158	178	1.55
14	316	15	1	0	99	14.07
316	14	12	2	258	214	2.84
309	310	317	2	46	35	1.68
310	309	301	1	26	15	2.46
317	310	117	3	26	23	0.55
317	310	309	2	10	15	1.52
8	318	26	2	666	781	4.26

	318	8	7	1	0	18	6.00
	318	8	10	2	684	703	0.74
	26	318	8	2	684	721	1.41
	318	26	25	3	11	32	4.64
	318	26	206	2	656	749	3.52
	320	25	7	2	85	0	13.04
	320	119	120	1	343	336	0.36
	9	319	11	2	72	199	10.89
	319	9	7	2	397	495	4.64
	319	9	10	1	76	59	2.13
	319	11	12	3	8	0	3.89
	319	11	13	2	191	199	0.55
	33	322	301	2	440	434	0.28
	301	322	33	2	254	258	0.25
	312	323	89	2	1437	1427	0.27
Main Turns	28	4	205	1	107	107	0.02
	28	4	307	2	166	164	0.18
	28	4	309	3	10	10	0.08
	87	3	310	3	6	17	3.37
	87	3	311	1	106	101	0.52
	87	3	322	2	33	31	0.29
	119	2	26	1	0	19	6.16
	119	2	304	3	252	228	1.55
	119	2	305	2	91	89	0.17
	203	1	234	3	28	27	0.27
	203	1	312	2	802	795	0.25
	117	4	28	1	32	32	0.08
	117	4	205	2	937	947	0.32
	117	4	307	3	125	125	0.01
	26	2	304	2	492	547	2.43
	26	2	305	1	164	202	2.80
	248	5	6	1	37	37	0.04
	248	5	314	3	18	18	0.04
	234	1	296	2	221	221	0.01
	234	1	312	3	383	379	0.20
	296	1	77	3	18	18	0.04
	296	1	234	2	393	378	0.76
	296	1	312	1	252	253	0.06
	293	5	248	3	151	150	0.07
	293	5	314	2	1667	1671	0.11
	294	4	28	3	208	213	0.31
	294	4	307	1	611	612	0.02
	294	4	309	2	1293	1281	0.34
	304	2	26	2	555	570	0.65
	304	2	305	3	68	59	1.16
	305	2	26	3	281	304	1.37
	305	2	304	1	75	63	1.46
	309	3	87	1	0	77	12.41
	309	3	311	2	1315	1314	0.02
	309	3	322	3	43	43	0.00
	307	4	28	2	82	82	0.04

307	4	205	3	773	767	0.23
307	4	309	1	73	71	0.29
311	1	77	2	927	939	0.40
311	1	234	1	504	486	0.80
311	1	296	3	257	261	0.27
313	5	6	2	2076	2069	0.15
313	5	248	1	113	113	0.05
322	3	87	2	114	105	0.89
322	3	310	1	59	58	0.14
322	3	311	3	266	271	0.28
323	3	87	3	233	217	1.08
323	3	310	2	1025	1026	0.02
323	3	322	1	178	184	0.42

Table E.9: GEH results of the base model for every link in the network.

Link no.	Street name	Modelled volume	Observed volume	GEH
8	R44	2113	2106	0.16
9	Ackermann	13	185	17.31
9	Ackermann	0	28	7.48
10	Jean	76	64	1.49
10	Jean	15	35	3.98
11	Cruse	8	26	4.51
11	Cruse	0	22	6.63
12	Vrede	347	323	1.32
12	Vrede	443	437	0.30
22	Skool	162	204	3.09
40	Noordwal-Wes	280	284	0.23
40	Noordwal-Wes	252	253	0.04
41	Noordwal-Wes	252	253	0.04
41	Noordwal-Wes	280	284	0.23
42	Noordwal-Wes	280	284	0.23
42	Noordwal-Wes	252	253	0.04
47	Van Reede	283	281	0.14
47	Van Reede	322	323	0.04
56	Barry	186	188	0.14
56	Barry	67	67	0.06
100	Bird	544	538	0.28
105	Doornbosch	145	149	0.36
105	Doornbosch	348	399	2.66
106	Doornbosch	410	407	0.14
106	Doornbosch	372	372	0.01
107	Doornbosch	372	372	0.01
107	Doornbosch	410	407	0.14
147	Suidwal	343	336	0.36
229	R44	830	822	0.30
232	R44	1094	1104	0.31
233	R44	1817	1821	0.08
234	Piet Retief	656	749	3.52
234	Piet Retief	835	893	1.97
236	Piet Retief	696	710	0.51
236	Piet Retief	666	613	2.11
237	Piet Retief	696	684	0.47
237	Piet Retief	605	558	1.94
238	Piet Retief	704	667	1.41
238	Piet Retief	605	537	2.84
248	Koch	397	348	2.54
248	Koch	227	189	2.64
249	Koch	214	196	1.28
249	Koch	397	512	5.39
251	Koch	191	210	1.32
251	Koch	547	586	1.62
252	Koch	635	640	0.22
252	Koch	895	902	0.25
253	Koch	895	902	0.25

253	Koch	635	640	0.22
254	Koch	158	178	1.55
254	Koch	28	29	0.24
257	Trumali	55	55	0.00
257	Trumali	263	263	0.02
260	Mill	677	680	0.12
262	Piet Retief	160	167	0.57
264	Piet Retief	454	458	0.21
264	Piet Retief	399	402	0.13
278	Dorp	376	375	0.07
278	Dorp	396	396	0.02
279	Dorp	396	396	0.02
279	Dorp	376	375	0.07
280	Dorp	376	375	0.07
280	Dorp	396	396	0.02
281	Dorp	376	375	0.07
281	Dorp	396	396	0.02
283	Dorp	445	427	0.87
283	Dorp	651	646	0.19
284	Dorp	651	646	0.19
284	Dorp	605	594	0.44
285	Dorp	651	646	0.19
285	Dorp	605	594	0.44
286	Dorp	719	707	0.47
286	Dorp	604	594	0.39
287	Dorp	604	602	0.07
287	Dorp	788	830	1.48
288	Dorp	604	602	0.07
288	Dorp	856	891	1.17
289	Dorp	604	602	0.07
289	Dorp	925	891	1.13
291	Dorp	663	648	0.58
291	Dorp	478	482	0.20
334	R44	2113	2106	0.16
336	R44	1817	1821	0.08
337	R44	1817	1821	0.08
341	R44	2113	2106	0.16
344	R44	945	957	0.40
347	R44	1817	1821	0.08
348	Piet Retief	559	569	0.41
348	Piet Retief	391	395	0.20
349	Piet Retief	454	456	0.11
349	Piet Retief	559	569	0.41
350	Piet Retief	623	639	0.65
350	Piet Retief	819	838	0.67
351	Piet Retief	819	838	0.67
351	Piet Retief	623	639	0.65
352	Suidwal	323	350	1.47
352	Suidwal	356	367	0.59
354	R44	1090	1101	0.33
355	R44	1094	1104	0.31

356	R44	1377	1362	0.41
357	R44	1358	1434	2.05
358	Van Reede	929	920	0.31
358	Van Reede	903	901	0.06
359	Van Reede	903	901	0.06
359	Van Reede	929	920	0.31
360	Van Reede	884	879	0.18
360	Van Reede	792	791	0.04
361	Van Reede	792	791	0.04
361	Van Reede	884	879	0.18
362	Van Reede	792	758	1.24
362	Van Reede	922	893	0.98
363	Van Reede	922	893	0.98
363	Van Reede	792.464918	758	1.24
365	R44	1437	1427	0.27
366	R44	1687	1686	0.03
367	R44	1687	1686	0.03
369	R44	2189	2182	0.14
370	R44	1684	1668	0.40
371	Dorp	819	811	0.29
371	Dorp	294	294	0.01
372	Dorp	294	294	0.01
372	Dorp	819	811	0.29
373	Park	28	29	0.24
373	Park	158	178	1.55
374	Piet Retief	261	230	1.97
374	Piet Retief	258	214	2.84
375	n.a.	46	72	3.43
375	n.a.	26	45	3.15
376	n.a.	51	37	2.15
376	n.a.	35	38	0.43
377	Piet Retief	666	781	4.26
377	Piet Retief	684	721	1.41
378	Piet Retief	684	721	1.41
378	Piet Retief	666	781	4.26
379	Koch	417	363	2.74
379	Koch	85	0	13.04
380	Koch	343	336	0.36
381	Koch	229	209	1.37
381	Koch	474	554	3.55
382	Koch	547	571	1.00
382	Koch	199	199	0.01
383	Stelkor Parking	63	63	0.05
384	Saffraan	440	434	0.28
384	Saffraan	254	255	0.06
385	Saffraan	254	255	0.06
385	Saffraan	440	434	0.28
386	R44	1437	1427	0.27
387	R44	1437	1427	0.27

E.8 DELAY AT THE NODES FOR THE BASE MODEL

Table E.10: Delay per vehicle for every turn movement in the network for the base model.

Turn movement	Delay (s)	LOS
RT Ackermann into Piet Retief	30.65	D
LT Ackermann into Piet Retief	30.65	D
LT Ackermann into Koch	0.00	
RT Ackermann into Koch	0.00	
LT Jean into Piet Retief	13.55	B
RT Jean into Piet Retief	13.55	B
RT Jean into Koch	9.38	A
LT Jean into Koch	9.38	A
LT Cruse into Piet Retief	27.77	D
RT Cruse into Piet Retief	27.77	D
LT Cruse into Koch	0.00	
RT Cruse into Koch	0.00	
LT Vrede into Piet Retief	13.31	B
RT Vrede into Koch	13.61	B
LT Vrede into Koch	13.61	B
LT Skool into Koch	9.55	A
RT Skool into Koch	9.55	A
RT Noordwal-Wes into Piet Retief	55.19	F
LT Noordwal-Wes into Piet Retief	13.58	B
LT Barry into Van Reede	21.21	C
RT Barry into Van Reede	57.10	F
LT Bird into Dorp	5.46	A
RT Bird into Dorp	11.63	B
LT Doornbosch into Van Reede	60.00	C
RT Doornbosch into Van Reede	90.00	F
RT Piet Retief into Skool	9.61	A
TT Piet Retief into Piet Retief at Skool St (N to S)	0.00	A
RT Piet Retief into Jean	0.00	A
TT Piet Retief into Piet Retief at Jean (N to S)	0.00	A
LT Piet Retief into Ackermann	0.00	A
TT Piet Retief into Piet Retief at Ackermann (S to N)	0.00	A
RT Piet Retief into Cruse	0.00	A
TT Piet Retief into Piet Retief at Cruse (N to S)	0.00	A
TT Piet Retief into Piet Retief at Jean (S to N)	0.00	A
LT Piet Retief into Jean	0.00	A
RT Piet Retief into Vrede	6.01	A
TT Piet Retief into Piet Retief at Vrede (N to S)	6.01	A
TT Piet Retief into Piet Retief at Cruse (S to N)	0.00	A
LT Piet Retief into Cruse	0.00	A
TT Koch into Koch at Skool (S to N)	0.00	A

LT Koch into Ackermann	0.00	A
TT Koch into Koch at Ackermann (N to S)	0.00	A
LT Koch into Jean	0.00	A
TT Koch into Koch at Jean (N to S)	0.00	A
RT Koch into Ackermann	0.00	A
TT Koch into Koch at Ackermann (S to N)	0.00	A
LT Koch into Vrede	0.00	A
TT Koch into Koch at Vrede (N to S)	0.00	A
RT Koch into Cruse	0.00	A
TT Koch into Koch at Cruse (S to N)	0.00	A
TT Koch into Koch at Vrede (S to N)	2.93	A
RT Koch into Vrede	2.93	A
TT Koch into Koch at Van Reede (N to S)	0.00	A
RT Koch into Van Reede	0.00	A
TT Koch into Koch at Van Reede (S to N)	14.75	B
LT Koch into Van Reede	14.75	B
LT Piet Retief into Dorp	12.87	B
TT Piet Retief into Mill	12.02	B
RT Piet Retief into Dorp	12.02	B
TT Dorp into Dorp at Bird (E to W)	12.87	B
RT Dorp into Piet Retief	12.41	B
LT Dorp into Mill	9.77	A
TT Dorp into Dorp at Piet Retief / Mill (W to E)	12.41	B
LT Piet Retief into Noordwal-Wes	0.00	A
TT Piet Retief into Piet Retief at Noordwal-Wes (N to S)	0.00	A
RT Piet Retief into Noordwal-Wes	10.71	B
TT Piet Retief into Piet Retief at Noordwal-Wes (S to N)	0.00	A
RT Van Reede into Barry	67.98	F
TT Van Reede into Van Reede at Barry (W to E)	0.00	A
LT Van Reede into Barry	0.00	A
TT Van Reede into Van Reede at Barry (E to W)	0.00	A
LT Van Reede into Doornbosch	10.00	
TT Van Reede into Van Reede at Doornbosch (W to E)	10.00	
RT Van Reede into Koch	10.59	B
LT Van Reede into Koch	10.59	B
RT Van Reede into Doornbosch	60.00	A
TT Van Reede into Van Reede at Doornbosch (E to W)	0.00	A
TT Dorp into Dorp at Bird (W to E)	0.00	A
LT Dorp into Piet Retief	7.08	A
TT Dorp into Dorp at Mill (E to W)	9.04	A
RT Dorp into Mill	9.04	A
LT Park into Piet Retief	0.00	
RT Park into Koch	0.00	
RT Piet Retief into Park	0.00	
TT Piet Retief into Piet Retief at Vrede (S to N)	0.00	A

LT Piet Retief into Vrede	0.00	A
TT Piet Retief into Piet Retief at PRG traffic signal (S to N)	3.15	A
RT Piet Retief into Ackermann	0.00	A
TT Piet Retief into Piet Retief at Ackermann (N to S)	0.00	A
TT Piet Retief into Piet Retief at PRG traffic signal (N to S)	3.20	A
LT Piet Retief into Skool	0.00	A
TT Piet Retief into Piet Retief at Skool (S to N)	0.00	A
TT Koch into Koch at Skool (N to S)	0.00	A
TT Koch into Koch at Jean (S to N)	1.33	A
RT Koch into Jean	1.33	A
LT Koch into Cruse	0.00	A
TT Koch into Koch at Cruse (N to S)	0.00	A
RT Van Reede (die Boord) into Strand S	63.88	E
TT Van Reede into Van Reede at Strand (W to E)	56.50	E
LT Van Reede (die Boord) into Strand N	56.50	E
LT Doornbosch into Strand S	51.91	D
RT Doornbosch into Strand N	51.91	D
TT Doornbosch into Saffraan (E to W)	51.91	D
RT Suidwal W into Piet Retief S at roundabout	20.83	C
LT Suidwal W into Piet Retief N at roundabout	20.83	C
TT Suidwal into Suidwal (W to E)	20.83	C
LT upper Strand N into Dorp E	61.62	E
TT upper Strand into Strand (N to S)	60.02	E
RT Strand N into Van Reede W	77.66	E
TT Strand into Strand at Van Reede (N to S)	80.96	F
LT Strand N into Van Reede E	43.14	D
TT Piet Retief into Piet Retief at Suidwal/roundabout (S to N)	12.25	B
RT Piet Retief S into Suidwal E	12.25	B
RT Trumali into Strand	32.59	C
LT Trumali into Strand	49.82	D
TT Dorp into lower Dorp (E to W)	76.15	E
LT Dorp E into Strand S	61.88	E
LT lower Dorp into Strand N	58.87	E
TT lower Dorp into Dorp (W to E)	58.87	E
RT lower Dorp into Strand S	268.67	F
LT Strand N into Trumali	64.61	E
TT Strand into Strand at Trumali (N to S)	34.06	C
LT Strand S into Van Reede (die Boord)	36.06	D
RT Strand S into Van Reede E	95.49	F
TT Strand into Strand at Van Reede (S to N)	110.18	F
TT Piet Retief into Piet Retief at Suidwal/roundabout (N to S)	17.59	C
LT Piet Retief N into Suidwal E	17.59	C
LT Suidwal E into Piet Retief S	14.96	B
RT Suidwal E into Piet Retief N	14.96	B
RT Strand S into Doornbosch	37.77	D

TT Strand into Strand at Saffraan/Doornbosch (S to N)	71.73	E
LT Strand into Saffraan	39.00	D
TT Van Reede into Van Reede (die Boord) (E to W)	60.88	E
LT Van Reede E into Strand S	44.70	D
RT Van Reede E into Strand N	60.88	E
TT Strand into upper Strand at Dorp (S to N)	38.56	D
RT Strand S into Dorp E	111.50	F
LT Strand S into lower Dorp W	40.26	D
TT Strand into Strand at Trumali (S to N)	59.98	E
RT Strand S into Trumali	196.27	F
TT Saffraan into Doornbosch (W to E)	50.79	D
RT Saffraan into Strand S	50.79	D
LT Saffraan into Strand N	60.06	E
LT Strand N into Doornbosch	32.29	C
TT Strand into Strand at Doornbosch/Saffraan (N to S)	39.69	D
RT Strand N into Saffraan	48.52	D

Table E.11: Control delay, level of service and back of queue per turning movement at main node 1 (intersection 5 in terms of the numbering system used for the traffic volume study).

R44 / Dorp Signalised Intersection									
Approach	N		E		S			W	
Lane Group	LT	T	L	T	LT	T	R	LT	R
d_i, Lane Group Delay (s)	61.62	60.02	61.88	76.15	22.59	21.44	97.74	58.83	268.67
LOS	E	E	E	E	C	C	F	E	F
d_A, Approach Delay (s/veh)	60.82		67.10		44.62			138.65	
Approach LOS	E		E		D			F	
d_I, Intersection Delay (s/veh)	68.23								
Intersection LOS	E								
Q, Average Back of Queue (veh)	19.15	18.77	17.92	11.26	12.79	12.59	31.05	13.04	26.50
Q_{90} Percentile Back of Queue (veh)	28.93	28.38	27.14	17.48	19.68	19.39	46.61	20.05	39.82

Table E.12: Control delay, level of service and back of queue per turning movement at main node 2 (intersection 9 in terms of the numbering system used for the traffic volume study).

Piet Retief / Suidwal Roundabout									
Approach	N		E		S		W		
Movement	L	T	L	R	T	R	L	T	R
d, Movement Delay (s/veh)	17.59	17.59	14.96	14.96	12.25	12.25	20.83	20.83	20.83
LOS	C	C	B	B	B	B	C	C	C
d_A, Approach Delay (s/veh)	17.59		14.96		12.25		20.83		
Approach LOS	C		B		B		C		
d_I, Intersection Delay (s/veh)	15.91								
Intersection LOS	C								
Q_{95}, 95% Queue Length (veh)	7.00		3.55		4.89		4.87		

Table E.13: Control delay, level of service and back of queue per turning movement at main node 3 (intersection 4 in terms of the numbering system used for the traffic volume study).

R44 / Saffraan Signalised Intersection									
Approach	N			E	S			W	
Lane Group	L	C	R	C	L	C	R	L	C
d_i, Lane Group Delay (s/veh)	32.29	39.69	48.52	51.69	27.20	53.72	26.28	60.06	50.81
LOS	C	D	D	D	C	D	C	E	D
d_A, Approach Delay (s/veh)	39.58			51.69	52.88			56.41	
Approach LOS	D			D	D			E	
d_I, Intersection Delay (s/veh)	47.64								
Intersection LOS	D								
Q, Average Back of Queue (veh)	7.15	36.97	6.66	5.77	1.14	59.18	0.00	11.89	6.74
Q_{90} Percentile Back of Queue (veh)	11.58	55.47	10.87	9.56	2.16	88.77	0.00	18.39	10.98

Table E.14: Control delay, level of service and back of queue per turning movement at main node 4 (intersection 2 in terms of the numbering system used for the traffic volume study).

R44 / Van Reede Signalised Intersection										
Approach	N			E		S			W	
Lane Group	L	C	R	L	C	L	C	R	C	R
d_i, Lane Group Delay (s/veh)	43.14	80.96	77.66	44.70	61.56	36.06	104.18	117.21	56.50	60.89
LOS	D	F	E	D	E	D	F	F	E	E
d_A, Approach Delay (s/veh)	76.54			47.53		101.23			58.15	
Approach LOS	E			D	A	F			E	
d_I, Intersection Delay (s/veh)	81.07									
Intersection LOS	F									
Q, Average Back of Queue (veh)	4.35	31.89	1.77	34.26	6.98	6.71	24.86	10.30	7.25	4.85
Q_{90} Percentile Back of Queue (veh)	7.44	47.86	3.27	51.40	11.34	10.95	37.38	16.10	11.73	8.20

Table E.15: Control delay, level of service and back of queue per turning movement at main node 5 (intersection 1 in terms of the numbering system used for the traffic volume study).

R44 / Trumali Signalised Intersection						
Approach	N		E		S	
Lane Group	L	C	L	R	C	R
d_i, Lane Group Delay (s/veh)	64.61	34.06	49.82	32.59	196.27	59.98
LOS	E	C	D	C	F	E
d_A, Approach Delay (s/veh)	36.60		38.17		189.26	
Approach LOS	D		D		F	
d_I, Intersection Delay (s/veh)	118.89					
Intersection LOS	F					
Q, Average Back of Queue (veh)	6.73	58.98	0.65	1.01	165.58	4.68
Q_{90} Percentile Back of Queue (veh)	10.97	88.47	1.26	1.93	248.37	7.94

Table E.16: Control delay, level of service and back of queue per turning movement at node 216 (intersection 6 in terms of the numbering system used for the traffic volume study).

Dorp / Piet Retief Roundabout						
Approach	N	E		S	W	
Lane		Lane 1	Lane 2	Lane 1	Lane 1	Lane 2
Movements		L1	T, R1	T, R1	L1	T, R1
d_i, Delay per Lane (s/veh)		7.08	9.04	12.02	9.77	12.41
LOS		A	A	B	A	B
d_A, Approach Delay (s/veh)		8.22		12.02	11.28	
Approach LOS		A		B	B	
d_I, Intersection Delay (s/veh)	10.10					
Intersection LOS	B					
Q_95, 95% Queue Length (veh)		1.54	2.63	3.11	1.82	3.02

E.9 VMT, VHT AND MEAN SPEED FOR THE BASE MODEL

Table E.17: VMT (in km) per O-D pair for the base model.

VMT 7-8AM		DESTINATIONS																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
ORIGINS	1	0.00	287.60	69.14	37.44	273.43	462.81	1599.63	282.59	413.83	241.34	23.99	282.74	200.06	11.35	520.93	24.74	5.68	72.52
	2	138.34	n.a.	n.a.	n.a.	21.11	1.87	3.23	0.81	10.14	0.40	n.a.	26.53	34.45	3.55	85.07	2.40	0.38	13.81
	3	3.20	0.04	n.a.	n.a.	11.01	1.06	4.66	2.16	0.67	1.53	n.a.	n.a.	n.a.	n.a.	10.16	n.a.	n.a.	0.39
	4	9.98	0.15	n.a.	n.a.	69.17	15.40	146.29	22.25	23.68	50.12	1.95	1.15	4.67	n.a.	58.16	11.86	0.88	1.02
	5	242.81	10.46	n.a.	19.74	n.a.	11.07	53.53	7.72	55.09	26.81	1.72	100.68	54.01	2.77	99.89	3.43	0.61	22.55
	6	358.30	6.08	n.a.	23.27	34.65	n.a.	6.17	34.01	66.29	153.42	6.60	1.47	15.08	2.29	25.45	60.08	11.42	33.73
	7	1217.58	20.29	n.a.	104.77	129.57	15.17	0.00	2.48	4.60	7.06	n.a.	1.68	8.58	0.64	3.33	11.03	56.78	115.69
	8	4.47	n.a.	n.a.	0.70	0.69	0.21	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	9	406.59	14.48	n.a.	26.79	76.20	42.32	11.73	n.a.	n.a.	35.43	4.90	0.51	17.14	2.67	27.41	90.45	7.21	36.14
	10	248.20	8.43	n.a.	17.35	102.37	29.02	8.62	n.a.	12.51	0.00	5.35	0.45	13.17	1.88	85.96	62.89	5.45	23.80
	11	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	12	348.83	24.04	n.a.	n.a.	62.17	2.77	n.a.	n.a.	7.39	0.65	n.a.	n.a.	3.09	0.65	11.35	18.71	2.19	38.67
	13	435.29	31.81	n.a.	8.17	72.48	46.09	n.a.	n.a.	15.54	1.29	n.a.	3.56	n.a.	0.55	2.74	21.60	1.92	39.46
	14	82.53	2.15	n.a.	16.62	18.78	68.67	n.a.	n.a.	93.12	12.46	20.48	21.94	37.75	n.a.	n.a.	8.85	n.a.	n.a.
	15	144.95	7.06	n.a.	1.14	15.64	31.34	24.94	6.90	28.96	4.11	n.a.	7.25	4.27	121.39	0.00	2.99	0.36	11.80
	16	180.51	9.89	n.a.	15.34	27.43	68.32	13.86	n.a.	125.14	9.87	n.a.	28.38	15.45	1.43	7.13	n.a.	0.84	15.72
	17	148.83	4.51	n.a.	n.a.	2.20	6.86	21.27	4.43	27.15	6.16	n.a.	4.59	2.69	n.a.	6.16	0.32	0.00	15.20
	18	11.71	4.50	1.78	0.83	4.26	6.37	22.65	7.80	25.31	8.63	n.a.	n.a.	3.85	n.a.	6.24	n.a.	0.12	n.a.

13156.62

Table E.18: VHT (in min) per O-D pair for the base model.

VHT 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0.00	612.20	190.66	102.62	881.91	1282.25	4216.30	912.62	1186.21	657.35	69.31	842.08	597.71	34.51	1795.22	79.78	21.93	434.51
	2	290.57	0.00	0.00	0.00	82.02	5.42	8.52	3.01	30.45	1.11	0.00	81.55	106.66	11.30	355.92	8.82	2.73	32.82
	3	7.14	0.16	0.00	0.00	34.36	2.73	10.58	8.13	1.92	3.98	0.00	0.00	0.00	0.00	36.28	0.00	0.00	0.96
	4	24.89	0.60	0.00	0.00	193.27	45.12	369.27	93.72	72.22	137.69	6.06	2.99	12.77	0.00	212.31	39.31	4.03	2.76
	5	647.86	52.70	9.32	50.69	0.00	25.20	111.20	25.19	145.41	65.36	4.61	270.39	144.74	7.69	364.97	10.49	2.61	64.77
	6	1464.59	39.74	0.00	197.64	208.32	0.00	23.49	149.53	160.67	324.02	16.45	2.91	32.87	5.51	57.75	134.57	78.16	142.18
	7	2947.14	63.05	0.00	304.99	309.16	40.31	0.00	7.53	10.03	13.86	0.00	3.13	17.49	1.44	7.12	23.35	197.00	297.48
	8	11.29	0.00	0.00	2.33	1.80	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	932.98	39.36	0.00	66.23	177.96	113.73	27.29	0.00	0.00	40.21	12.70	0.73	32.42	6.30	58.50	189.24	13.14	87.53
	10	550.43	21.62	0.00	39.95	225.16	69.76	19.22	0.00	23.34	0.00	9.70	0.60	22.13	3.93	166.63	120.19	9.47	55.67
	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	670.16	56.40	0.00	0.00	162.67	7.89	0.00	0.00	21.74	1.49	0.00	0.00	6.15	1.66	25.51	40.98	4.05	79.83
	13	809.03	72.18	0.00	18.30	184.96	106.21	0.00	0.00	27.17	1.90	0.00	6.53	0.00	1.29	5.60	43.04	3.31	79.28
	14	137.15	4.34	0.00	33.83	44.35	167.35	0.00	0.00	192.59	21.50	50.83	48.53	77.92	0.00	0.00	18.29	0.00	0.00
	15	249.97	16.08	0.00	2.52	44.18	78.48	56.14	13.11	66.42	8.14	0.00	17.56	10.09	231.84	0.00	7.84	0.46	22.75
	16	323.95	23.78	0.00	35.38	80.99	155.21	32.07	0.00	236.93	16.51	0.00	55.71	28.37	2.84	10.31	0.00	1.22	31.32
	17	319.71	22.87	0.00	0.00	10.40	22.12	62.26	17.70	85.64	17.64	0.00	15.05	8.93	0.00	29.59	1.34	0.00	36.69
	18	25.65	7.81	4.22	2.00	12.23	15.94	54.17	23.14	67.35	21.88	0.00	0.00	10.61	0.00	19.51	0.00	0.41	0.00

34707.81

Table E.19: Average travel speeds (in km/h) per O-D pair for the base model.

VCUR 7-8AM		DESTINATIONS																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
ORIGINS	**1**	0.00	28.19	21.76	21.89	18.60	21.66	22.76	18.58	20.93	22.03	20.77	20.15	20.08	19.74	17.41	18.60	15.55	10.01
	2	28.57	0.00	0.00	0.00	15.44	20.68	22.74	16.05	19.97	21.65	0.00	19.52	19.38	18.82	14.34	16.32	8.31	25.25
	3	26.92	15.17	0.00	0.00	19.22	23.35	26.44	15.94	21.04	23.14	0.00	0.00	0.00	0.00	16.81	0.00	0.00	24.23
	4	24.05	15.18	0.00	0.00	21.47	20.48	23.77	14.24	19.67	21.84	19.35	23.08	21.95	0.00	16.44	18.11	13.07	22.24
	5	22.49	11.91	25.03	23.37	0.00	26.35	28.88	18.39	22.73	24.61	22.43	22.34	22.39	21.64	16.42	19.64	14.05	20.89
	6	14.68	9.19	7.98	7.07	9.98	0.00	15.76	13.65	24.76	28.41	24.09	30.41	27.53	24.96	26.56	26.79	8.77	14.24
	7	24.79	19.30	22.88	20.61	25.15	22.59	0.00	19.76	27.53	30.55	0.00	32.25	29.44	26.76	28.16	28.35	17.29	23.33
	8	23.73	0.00	0.00	17.96	23.01	9.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	26.15	22.07	26.01	24.27	27.46	22.32	25.79	0.00	0.00	52.87	23.16	41.56	31.71	25.47	28.32	28.68	32.91	24.78
	10	27.06	23.40	27.75	26.06	28.98	24.96	26.90	0.00	32.16	0.00	33.07	45.23	35.69	28.76	31.14	31.40	34.51	25.65
	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	31.23	25.58	0.00	0.00	22.93	21.08	0.00	0.00	20.39	26.09	0.00	0.00	30.13	23.46	26.93	27.39	32.50	29.06
	13	32.28	26.44	0.00	26.77	23.51	26.03	0.00	0.00	34.33	40.61	0.00	32.73	0.00	25.41	29.64	30.11	34.81	29.86
	14	36.10	29.69	0.00	29.48	25.40	24.62	0.00	0.00	29.01	34.78	24.17	27.12	29.07	0.00	0.00	29.02	0.00	0.00
	15	34.79	26.34	0.00	27.07	21.23	23.96	26.66	31.57	26.16	30.30	0.00	24.77	25.36	31.42	0.00	22.87	47.92	31.13
	16	33.43	24.95	0.00	26.01	20.32	26.41	25.94	0.00	31.69	35.89	0.00	30.57	32.68	30.24	41.46	0.00	41.23	30.12
	17	27.93	11.83	0.00	0.00	12.68	18.62	20.50	15.00	19.02	20.96	0.00	18.31	18.08	0.00	12.49	14.37	0.00	24.85
	18	27.39	34.57	25.27	24.87	20.90	23.96	25.09	20.23	22.55	23.66	0.00	0.00	21.74	0.00	19.18	0.00	17.65	0.00

Table E.20: Travelling distance between each origin and destination in the network (stays the same for all alternatives).

SKIM MATRIX Distance 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0.00	1.40	1.55	1.82	1.77	2.26	2.44	2.40	2.98	3.22	2.96	2.83	2.72	2.68	2.03	2.07	1.44	0.64
	2	1.42	n.a.	n.a.	n.a.	0.66	1.16	1.33	1.29	1.88	2.12	n.a.	1.73	1.61	1.58	0.92	0.97	0.34	1.47
	3	1.56	0.43	n.a.	n.a.	0.80	0.81	0.98	0.94	1.53	1.77	n.a.	n.a.	n.a.	n.a.	1.06	n.a.	n.a.	1.61
	4	1.84	0.72	n.a.	n.a.	0.60	0.71	0.88	0.84	1.42	1.66	1.40	1.81	1.84	n.a.	1.35	1.39	0.76	1.90
	5	1.79	0.66	n.a.	0.60	n.a.	1.05	1.22	1.19	1.77	2.01	1.75	1.54	1.43	1.39	0.74	0.78	0.52	1.84
	6	2.28	1.16	n.a.	0.70	1.05	n.a.	0.35	0.31	0.89	1.13	0.87	1.28	1.31	1.45	1.60	1.65	1.20	2.34
	7	2.52	1.40	n.a.	0.94	1.29	1.77	0.00	0.55	1.13	1.37	n.a.	1.51	1.55	1.69	1.84	1.89	1.44	2.58
	8	2.36	n.a.	n.a.	0.78	1.12	0.25	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	9	3.06	1.94	n.a.	1.48	1.71	0.95	2.48	n.a.	n.a.	0.35	0.21	0.61	0.65	0.78	0.94	0.99	1.75	3.12
	10	3.24	2.12	n.a.	1.66	1.89	1.13	2.67	n.a.	0.41	0.00	0.39	0.80	0.83	0.97	1.12	1.17	1.93	3.30
	11	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	12	2.85	1.73	n.a.	n.a.	1.54	1.26	n.a.	n.a.	0.56	0.80	n.a.	n.a.	0.48	0.62	0.77	0.82	1.58	2.91
	13	2.74	1.61	n.a.	1.83	1.43	1.30	n.a.	n.a.	0.59	0.83	n.a.	0.48	n.a.	0.50	0.66	0.71	1.47	2.79
	14	2.36	1.23	n.a.	1.65	1.04	1.35	n.a.	n.a.	0.64	0.88	2.79	0.53	0.42	n.a.	n.a.	0.69	n.a.	n.a.
	15	2.05	0.92	n.a.	1.34	0.74	1.60	1.96	1.29	0.89	1.13	n.a.	0.79	0.67	0.31	0.00	0.40	0.78	2.10
	16	2.09	0.97	n.a.	1.39	0.78	1.64	2.00	n.a.	0.93	1.17	n.a.	0.82	0.71	0.68	0.47	n.a.	0.82	2.15
	17	1.46	0.34	n.a.	n.a.	0.52	1.20	1.37	1.34	1.69	1.93	n.a.	1.58	1.47	n.a.	0.78	0.82	0.00	1.52
	18	0.66	1.47	1.62	1.89	1.84	2.33	2.50	2.47	3.05	3.29	n.a.	n.a.	2.79	n.a.	2.10	n.a.	1.51	n.a.

322.4069

Table E.21: Average travel time (in min) per vehicle per O-D pair for the base model.

SKIM MATRIX t_{CUR} 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0.00	2.98	4.28	4.98	5.70	6.27	6.42	7.75	8.55	8.78	8.56	8.44	8.12	8.16	7.00	6.69	5.57	3.86
	2	2.98	0.00	0.00	0.00	2.58	3.36	3.51	4.84	5.64	5.87	0.00	5.31	4.99	5.03	3.87	3.56	2.44	3.50
	3	3.47	1.71	0.00	0.00	2.50	2.08	2.22	3.55	4.35	4.58	0.00	0.00	0.00	0.00	3.79	0.00	0.00	3.99
	4	4.59	2.83	0.00	0.00	1.69	2.07	2.21	3.54	4.35	4.57	4.35	4.70	5.04	0.00	4.92	4.60	3.49	5.12
	5	4.77	3.34	1.65	1.55	0.00	2.39	2.54	3.87	4.67	4.90	4.68	4.14	3.82	3.86	2.70	2.39	2.21	5.29
	6	9.34	7.58	5.92	5.97	6.30	0.00	1.32	1.37	2.17	2.39	2.17	2.52	2.86	3.48	3.64	3.70	8.23	9.86
	7	6.11	4.35	2.69	2.74	3.07	4.71	0.00	1.67	2.47	2.69	0.00	2.82	3.16	3.78	3.94	4.00	5.00	6.63
	8	5.96	0.00	0.00	2.60	2.93	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	7.02	5.26	3.60	3.66	3.98	2.55	5.78	0.00	0.00	0.40	0.54	0.88	1.23	1.84	2.01	2.07	3.18	7.54
	10	7.19	5.43	3.78	3.83	4.16	2.73	5.95	0.00	0.77	0.00	0.71	1.06	1.40	2.02	2.18	2.24	3.36	7.72
	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	5.48	4.05	0.00	0.00	4.03	3.59	0.00	0.00	1.63	1.83	0.00	0.00	0.96	1.58	1.74	1.80	2.92	6.00
	13	5.09	3.66	0.00	4.09	3.64	2.99	0.00	0.00	1.03	1.23	0.00	0.88	0.00	1.19	1.35	1.41	2.53	5.61
	14	3.91	2.49	0.00	3.36	2.47	3.28	0.00	0.00	1.32	1.52	6.93	1.17	0.86	0.00	0.00	1.43	0.00	0.00
	15	3.53	2.11	0.00	2.98	2.09	4.01	4.41	2.45	2.05	2.25	0.00	1.90	1.59	0.58	0.00	1.04	0.98	4.06
	16	3.76	2.33	0.00	3.20	2.31	3.72	4.63	0.00	1.77	1.96	0.00	1.62	1.30	1.34	0.68	0.00	1.20	4.28
	17	3.14	1.71	0.00	0.00	2.45	3.87	4.02	5.35	5.33	5.53	0.00	5.18	4.87	0.00	3.74	3.43	0.00	3.66
	18	1.44	2.55	3.84	4.55	5.27	5.84	5.99	7.32	8.12	8.35	0.00	0.00	7.69	0.00	6.56	0.00	5.14	0.00

E.10 ADJUSTED CONTROL BASE-MODEL DELAY AT MAIN NODES 1 AND 3

Table E.22: Adjusted control delay, level of service and back of queue per turning movement at main node 1 (intersection 5 in terms of the numbering system used for the traffic volume study).

R44 / Dorp Signalised Intersection (adjusted)									
Approach	N		E		S			W	
Lane Group	LT	T	L	T	LT	T	R	LT	R
d_i, Lane Group Delay (s)	61.62	60.02	61.88	76.15	40.28	38.56	111.50	58.83	268.67
LOS	E	E	E	E	D	D	F	E	F
d_A, Approach Delay (s/veh)	60.82		67.10		60.94			138.65	
Approach LOS	E		E		E			F	
d_I, Intersection Delay (s/veh)	68.23								
Intersection LOS	E								
Q, Average Back of Queue (veh)	19.15	18.77	17.92	11.26	17.45	17.64	31.30	13.04	26.50
Q_{90} Percentile Back of Queue (veh)	28.93	28.38	27.14	17.48	26.43	26.72	46.98	20.05	39.82

Table E.23: Adjusted control delay, level of service and back of queue per turning movement at main node 3 (intersection 4 in terms of the numbering system used for the traffic volume study).

R44 / Saffraan Signalised Intersection (adjusted)									
Approach	N			E	S			W	
Lane Group	L	C	R	C	L	C	R	L	C
di, Lane Group Delay (s/veh)	32.29	39.69	48.52	51.69	39.00	71.73	37.77	60.06	50.81
LOS	C	D	D	D	D	E	D	E	D
dA, Approach Delay (s/veh)	39.58			51.69	70.70			56.41	
Approach LOS	D			D	E			E	
dI, Intersection Delay (s/veh)	47.64								
Intersection LOS	D								
Q, Average Back of Queue (veh)	7.15	36.97	6.66	5.77	1.58	61.28	0.00	11.89	6.74
Q_{90} Percentile Back of Queue (veh)	11.58	55.47	10.87	9.56	2.94	91.91	0.00	18.39	10.98

F. CHAPTER 6 APPENDIX: THE NULL ALTERNATIVE

F.1 2000, 2012, 2012 AND 2105 TRAFFIC COUNT DATA FOR INTERSECTIONS 2, 4 AND 5

Table F.1: Traffic count data for the southern approach of the R44 / Van Reede intersection for the years 2000, 2012, 2013 and 2015.

SOUTH

VAN REEDE

Time		Turn 1							Turn 2							Turn 3						
Start	**End**	**2000**		**2012**	**2013**		**2015**		**2000**		**2012**	**2013**		**2015**		**2000**		**2012**	**2013**		**2015**	
06:00	06:15				1							60							9			
06:15	06:30				2							105							35			
06:30	06:45	0			3				77			255				14			63			
06:45	07:00	2	**2**	**18**	5	**11**	0		145	**222**	**651**	304	**724**	304		22	**36**	**209**	154	**261**	148	
07:00	07:15	5			29		37		203			459		378		75			207		188	
07:15	07:30	13			50		45		405			386		390		170			149		109	
07:30	07:45	22			71		59		377			326		284		112			139		138	
07:45	08:00	42	**82**	**203**	56	**206**	71	**212**	372	**1357**	**1423**	209	**1380**	209	**1261**	169	**526**	**676**	179	**674**	177	**612**
08:00	08:15	21			19		24		368			246		262		174			156		139	
08:15	08:30	13			19				285			326				102			184			
08:30	08:45	9			15				229			255				93			114			
08:45	09:00	10	**53**	**96**	20	**73**			222	**1104**	**1190**	265	**1092**			94	**463**	**595**	157	**611**		

Table F.2: Traffic count data for the southern approach of the R44 / Saffraan intersection for the years 2000, 2012, 2013 and 2015.

SOUTH

SAFFRAAN

Time		Turn 1							Turn 2							Turn 3						
Start	**End**	**2000**		**2012**	**2013**		**2015**		**2000**		**2012**	**2013**		**2015**		**2000**		**2012**	**2013**		**2015**	
06:00	06:15				2							61							0			
06:15	06:30				3							111							0			
06:30	06:45	5			18				63			229				1			0			
06:45	07:00	6	**11**	**33**	19	**42**			140	**203**	**630**	317	**718**			0	**1**	**5**	7	**7**		
07:00	07:15	7			7		11		228			381		353		0			20		16	
07:15	07:30	19			10		12		437			300		328		23			31		25	
07:30	07:45	5			9		4		423			303		246		32			9		22	
07:45	08:00	17	**48**	**48**	13	**39**	11	**38**	452	**1540**	**1361**	175	**1159**	227	**1154**	10	**65**	**64**	2	**62**	5	**68**
08:00	08:15	22			19				377			349				0			0			
08:15	08:30	27			19				359			275				1			1			
08:30	08:45	30			32				223			365				2			0			
08:45	09:00	25	**104**	**115**	22	**92**			248	**1207**	**1165**	186	**1175**			2	**5**	**1**	1	**2**		

Table F.3: Traffic count data for the southern approach of the R44 / Dorp intersection for the years 2000, 2012, 2013 and 2015.

SOUTH

DORP

Time		Turn 1							Turn 2							Turn 3						
Start	**End**	**2000**		**2012**	**2013**		**2015**		**2000**		**2012**	**2013**		**2015**		**2000**		**2012**	**2013**		**2015**	
06:00	06:15				9							55							12			
06:15	06:30				24							89							18			
06:30	06:45	10			38				55			165				12			25			
06:45	07:00	19	**29**	**103**	43	**114**			128	**183**	**464**	243	**552**			23	**35**	**103**	75	**130**		
07:00	07:15	35			34		56		163			251		254		41			89		115	
07:15	07:30	78			65		48		305			296		239		69			101		124	
07:30	07:45	63			63		64		279			224		209		121			74		117	
07:45	08:00	95	**271**	**234**	112	**274**	93	**261**	323	**1070**	**1031**	219	**990**	237	**939**	153	**384**	**390**	113	**377**	130	**486**
08:00	08:15	104			85				316			135				126			95			
08:15	08:30	79			76				252			225				70			96			
08:30	08:45	53			74				185			195				70			95			
08:45	09:00	52	**288**	**285**	61	**296**			171	**924**	**907**	189	**744**			63	**329**	**401**	102	**388**		

Table F.4: Traffic count data for the northern approach of the R44 / Van Reede intersection for the years 2000, 2012, 2013 and 2015.

NORTH

VAN REEDE

Time		Turn 7							Turn 8							Turn 9						
Start	**End**	**2000**		**2012**	**2013**		**2015**		**2000**		**2012**	**2013**		**2015**		**2000**		**2012**	**2013**		**2015**	
06:00	06:15				2							37							0			
06:15	06:30				2							71							0			
06:30	06:45	4			4				41			147				3			2			
06:45	07:00	5	**9**	**11**	4	**12**			73	**114**	**420**	242	**497**			3	**6**	**7**	2	**4**		
07:00	07:15	10			37		32		87			267		246		2			4		3	
07:15	07:30	21			57		55		118			259		224		4			11		4	
07:30	07:45	44			31		22		208			257		217		22			7		10	
07:45	08:00	22	**97**	**107**	15	**140**	19	**128**	259	**672**	**1069**	371	**1154**	226	**913**	17	**45**	**41**	20	**42**	11	**28**
08:00	08:15	28			18				193			315				11			12			
08:15	08:30	16			19				146			261				12			11			
08:30	08:45	20			14				113			296				10			10			
08:45	09:00	16	**80**	**45**	12	**63**			173	**625**	**995**	323	**1195**			11	**44**	**54**	6	**39**		

Table F.5: Traffic count data for the northern approach of the R44 / Saffraan intersection for the years 2000, 2012, 2013 and 2015.

NORTH

SAFFRAAN

Time		Turn 7							Turn 8							Turn 9						
Start	**End**	**2000**		**2012**	**2013**		**2015**		**2000**		**2012**	**2013**		**2015**		**2000**		**2012**	**2013**		**2015**	
06:00	06:15				0							40							7			
06:15	06:30				5							71							12			
06:30	06:45	0			6				34			129				17			25			
06:45	07:00	2	**2**	**75**	16	**27**			66	**100**	**402**	212	**452**			26	**43**	**16**	28	**72**		
07:00	07:15	14			39		33		110			237		278		26			32		42	
07:15	07:30	46			92		71		154			293		276		35			17		32	
07:30	07:45	49			62		85		183			253		250		45			28		46	
07:45	08:00	18	**127**	**164**	19	**212**	20	**209**	258	**705**	**1144**	215	**998**	186	**990**	70	**176**	**173**	68	**145**	57	**177**
08:00	08:15	2			5				177			260				59			82			
08:15	08:30	6			5				187			340				68			84			
08:30	08:45	3			1				137			226				37			56			
08:45	09:00	6	**17**	**265**	4	**15**			143	**644**	**996**	198	**1024**			60	**224**	**22**	73	**295**		

Table F.6: Traffic count data for the northern approach of the R44 / Dorp intersection for the years 2000, 2012, 2013 and 2015.

NORTH
DORP

Time		Turn 7							Turn 8							Turn 9						
Start	**End**	**2000**		**2012**	**2013**		**2015**		**2000**		**2012**	**2013**		**2015**		**2000**		**2012**	**2013**		**2015**	
06:00	06:15				1							47										
06:15	06:30				0							63										
06:30	06:45	0			1				41			89										
06:45	07:00	3	**3**	**16**	6	**8**			65	**106**	**381**	202	**401**									
07:00	07:15	8			6		4		89			195		224								
07:15	07:30	9			6		5		159			274		203								
07:30	07:45	12			4		7		160			199		217								
07:45	08:00	13	**42**	**30**	13	**29**	11	**27**	201	**609**	**915**	173	**841**	151	**795**							
08:00	08:15	30			12				181			239										
08:15	08:30	13			15				155			205										
08:30	08:45	11			3				125			195										
08:45	09:00	13	**67**	**51**	12	**42**			134	**595**	**810**	186	**825**									

F.2 NULL-ALTERNATIVE O-D MATRICES

Table F.7: 2020 null alternative O-D matrix.

2020 O/D MATRIX 7-8AM		DESTINATIONS																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
ORIGINS	1	0	238	83	24	179	237	762	137	161	87	9	116	85	5	297	14	5	130	
	2	113	0	0	0	37	2	3	1	6	0	0	18	25	3	107	3	1	11	
	3	34	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0	
	4	6	0	0	0	133	25	193	31	19	35	2	1	3	0	50	10	1	1	
	5	157	18	7	38	0	12	51	8	36	15	1	76	44	2	157	5	1	14	
	6	182	6	0	38	38	0	21	127	86	157	9	1	13	2	18	42	11	17	
	7	560	17	0	129	117	10	0	5	5	6	0	1	6	0	2	7	46	52	
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	
	9	154	9	0	21	52	52	5	0	20	118	27	1	31	4	34	106	5	13	
	10	89	5	0	12	63	30	4	0	35	0	16	1	18	2	89	62	3	8	
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	12	142	16	0	0	47	3	0	0	15	1	0	0	7	1	17	26	2	15	
	13	184	23	0	5	59	41	0	0	30	2	0	9	0	1	5	35	2	16	
	14	41	2	0	12	21	59	0	0	169	16	9	48	105	0	0	15	0	0	
	15	82	9	0	1	25	23	15	6	38	4	0	11	7	460	0	9	1	7	
	16	100	12	0	13	41	48	8	0	156	10	0	40	25	2	17	0	1	8	
	17	118	15	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12	
	18	21	4	1	1	3	3	10	4	10	3	0	0	2	0	3	0	0	0	9603

Table F.8: 2021 null alternative O-D matrix.

2021 O/D MATRIX 7-8AM		DESTINATIONS																		
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	
ORIGINS	**1**	0	245	85	25	185	244	784	141	166	89	10	119	88	5	306	14	5	134	
	2	116	0	0	0	38	2	3	1	6	0	0	18	25	3	110	3	1	11	
	3	35	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0	
	4	6	0	0	0	137	26	199	32	20	36	2	1	3	0	52	10	1	1	
	5	162	19	7	39	0	13	52	8	37	16	1	78	45	2	161	5	1	15	
	6	187	6	0	40	39	0	21	131	89	162	9	1	14	2	19	43	11	17	
	7	576	17	0	133	120	10	0	5	5	6	0	1	7	0	2	7	47	54	
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	
	9	159	9	0	22	53	53	6	0	21	121	28	1	32	4	35	109	5	14	
	10	91	5	0	12	65	31	4	0	36	0	16	1	19	2	91	64	3	9	
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	12	146	17	0	0	48	3	0	0	16	1	0	0	8	1	17	27	2	16	
	13	190	24	0	5	61	42	0	0	31	2	0	9	0	1	5	36	2	17	
	14	42	2	0	12	21	61	0	0	174	17	9	49	108	0	0	15	0	0	
	15	84	9	0	1	25	23	15	6	39	4	0	11	8	474	0	9	1	7	
	16	103	12	0	13	42	50	8	0	160	10	0	41	26	3	18	0	1	9	
	17	121	16	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12	
	18	21	4	1	1	3	3	11	4	10	3	0	0	2	0	4	0	0	0	9891

Table F.9: Null alternative at capacity O-D matrix.

Capacity O/D MATRIX 7-8AM		DESTINATIONS																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
ORIGINS	1	0	253	88	25	190	251	808	145	171	92	10	123	91	5	316	15	5	138	
	2	120	0	0	0	39	2	3	1	7	0	0	19	26	3	113	3	1	12	
	3	36	0	0	0	17	2	6	3	1	1	0	0	0	0	12	0	0	0	
	4	7	0	0	0	141	27	205	33	20	37	2	1	3	0	53	10	1	1	
	5	167	19	7	40	0	13	54	8	38	16	1	80	47	2	166	5	1	15	
	6	193	6	0	41	41	0	22	135	91	166	9	1	14	2	20	45	12	18	
	7	594	18	0	137	124	11	0	6	5	6	0	1	7	0	2	7	48	55	
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	
	9	163	9	0	22	55	55	6	0	21	125	29	1	33	4	36	112	5	14	
	10	94	5	0	13	67	31	4	0	37	0	17	1	19	2	94	66	3	9	
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	12	150	17	0	0	50	3	0	0	16	1	0	0	8	1	18	28	2	16	
	13	196	24	0	5	62	44	0	0	32	2	0	9	0	1	5	37	2	17	
	14	43	2	0	12	22	63	0	0	179	17	9	51	111	0	0	16	0	0	
	15	87	9	0	1	26	24	16	7	40	4	0	11	8	488	0	9	1	7	
	16	106	13	0	14	43	51	9	0	165	10	0	42	27	3	19	0	1	9	
	17	125	16	0	0	5	7	19	4	20	4	0	4	2	0	10	0	0	12	
	18	22	4	1	1	3	3	11	4	10	3	0	0	2	0	4	0	0	0	10188

F.3 NULL-ALTERNATIVE TRAVEL TIMES PER O-D PAIR AND DELAYS AT EVERY NODE

Table F.10: 2020 null-alternative travel time (in min) per vehicle per O-D pair.

2020 t_{CUR} 7-8AM		DESTINATIONS																	
		1.00	**2.00**	**3.00**	**4.00**	**5.00**	**6.00**	**7.00**	**8.00**	**9.00**	**10.00**	**11.00**	**12.00**	**13.00**	**14.00**	**15.00**	**16.00**	**17.00**	**18.00**
ORIGINS	**1.00**	0.00	3.31	8.53	9.43	9.21	13.18	13.30	18.01	19.16	19.40	19.18	19.40	18.95	16.22	13.12	10.57	17.57	9.04
	2.00	4.35	0.00	0.00	0.00	2.41	6.05	6.18	10.88	12.03	12.27	0.00	12.60	12.15	9.43	6.33	3.78	10.78	3.82
	3.00	7.74	1.76	0.00	0.00	2.32	4.73	4.86	9.56	10.71	10.95	0.00	0.00	0.00	0.00	6.23	0.00	0.00	7.21
	4.00	8.90	2.92	0.00	0.00	2.07	2.60	2.73	7.43	8.59	8.83	8.61	8.95	9.55	0.00	7.39	4.84	11.85	8.37
	5.00	8.08	4.26	1.72	1.62	0.00	2.83	2.95	7.66	8.81	9.05	8.83	12.98	12.54	9.81	6.71	4.16	2.97	7.56
	6.00	18.22	12.25	10.54	10.52	11.22	0.00	1.62	2.14	3.29	3.53	3.31	3.65	4.25	17.32	17.31	20.58	21.17	17.69
	7.00	10.77	4.79	3.09	3.07	3.77	7.77	0.00	2.52	3.67	3.91	0.00	4.04	4.63	17.71	17.70	20.96	13.72	10.24
	8.00	10.76	0.00	0.00	3.06	3.76	1.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9.00	12.13	6.15	4.44	4.43	5.12	3.20	9.25	0.00	0.00	0.42	0.72	1.07	1.66	14.74	14.73	17.99	20.35	11.60
	10.00	12.31	6.33	4.62	4.61	5.30	3.38	9.43	0.00	1.02	0.00	0.91	1.25	1.84	14.92	14.91	18.17	20.53	11.78
	11.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12.00	25.04	21.21	0.00	0.00	21.48	4.92	0.00	0.00	2.60	2.75	0.00	0.00	1.24	14.32	14.31	17.57	19.93	24.51
	13.00	24.50	20.67	0.00	4.97	20.94	3.74	0.00	0.00	1.41	1.57	0.00	1.15	0.00	13.78	13.77	17.03	19.39	23.97
	14.00	7.68	3.85	0.00	4.92	4.12	4.40	0.00	0.00	2.07	2.23	14.66	1.81	1.36	0.00	0.00	1.79	0.00	0.00
	15.00	7.29	3.46	0.00	4.53	3.74	11.62	8.40	9.72	9.29	9.45	0.00	9.03	8.58	1.34	0.00	1.27	2.18	6.76
	16.00	6.75	2.92	0.00	3.99	3.20	11.13	7.86	0.00	8.81	8.96	0.00	8.54	8.09	5.37	0.74	0.00	1.64	6.22
	17.00	5.86	2.03	0.00	0.00	3.32	6.84	6.97	11.67	13.77	13.92	0.00	13.51	13.06	0.00	7.23	4.68	0.00	5.33
	18.00	1.44	2.72	7.93	8.84	8.61	12.58	12.70	17.41	18.56	18.80	0.00	0.00	18.35	0.00	12.52	0.00	16.98	0.00

Table F.11: 2021 null-alternative travel time (in min) per vehicle per O-D pair.

2021 t_{CUR} 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0.00	3.55	9.75	10.65	10.49	15.28	15.40	21.12	22.38	22.63	22.40	22.32	21.83	18.57	15.07	12.03	21.56	10.23
	2	5.18	0.00	0.00	0.00	2.54	6.95	7.08	12.79	14.05	14.30	0.00	14.38	13.88	10.62	7.13	4.08	13.62	3.92
	3	9.47	1.77	0.00	0.00	2.43	5.61	5.74	11.46	12.72	12.96	0.00	0.00	0.00	0.00	7.02	0.00	0.00	8.21
	4	10.65	2.95	0.00	0.00	2.19	2.67	2.80	8.52	9.77	10.02	9.80	10.15	10.88	0.00	8.19	5.15	14.68	9.39
	5	9.77	4.49	1.73	1.63	0.00	2.86	2.99	8.70	9.96	10.21	9.99	14.87	14.37	11.11	7.62	4.57	3.16	8.51
	6	21.06	13.36	11.64	11.61	12.38	0.00	1.75	2.38	3.64	3.89	3.67	4.01	4.75	20.27	20.22	24.15	25.09	19.80
	7	12.71	5.01	3.29	3.26	4.03	8.85	0.00	2.85	4.11	4.36	0.00	4.48	5.21	20.74	20.69	24.62	16.74	11.44
	8	12.75	0.00	0.00	3.30	4.08	1.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	14.19	6.50	4.78	4.74	5.52	3.41	10.46	0.00	0.00	0.42	0.77	1.11	1.85	17.37	17.32	21.25	23.90	12.93
	10	14.39	6.70	4.97	4.94	5.71	3.61	10.66	0.00	1.09	0.00	0.96	1.31	2.04	17.57	17.52	21.45	24.09	13.13
	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	30.06	24.78	0.00	0.00	25.11	5.44	0.00	0.00	2.98	3.13	0.00	0.00	1.40	16.92	16.87	20.81	23.45	28.80
	13	29.41	24.14	0.00	5.34	24.46	4.00	0.00	0.00	1.55	1.69	0.00	1.25	0.00	16.28	16.23	20.16	22.80	28.15
	14	9.46	4.18	0.00	5.25	4.51	4.86	0.00	0.00	2.40	2.55	17.00	2.10	1.61	0.00	0.00	1.89	0.00	0.00
	15	9.07	3.79	0.00	4.86	4.12	13.29	9.61	11.24	10.83	10.98	0.00	10.53	10.04	1.52	0.00	1.32	2.46	7.81
	16	8.35	3.08	0.00	4.15	3.40	12.75	8.90	0.00	10.29	10.44	0.00	9.99	9.50	6.24	0.76	0.00	1.74	7.09
	17	7.41	2.13	0.00	0.00	4.04	7.83	7.96	13.67	16.18	16.32	0.00	15.88	15.38	0.00	8.63	5.58	0.00	6.15
	18	1.44	2.88	9.07	9.98	9.82	14.61	14.73	20.45	21.71	21.96	0.00	0.00	21.16	0.00	14.40	0.00	20.89	0.00

Table F.12: Null-alternative travel time (in min) per vehicle per O-D pair at capacity.

Capacity tCUR 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0.00	3.82	11.05	11.96	11.89	17.53	17.66	24.46	25.84	26.08	25.85	25.70	25.17	21.26	17.28	13.64	25.94	11.45
	2	6.10	0.00	0.00	0.00	2.70	7.92	8.04	14.85	16.23	16.46	0.00	16.50	15.97	12.06	8.08	4.44	16.75	4.00
	3	11.34	1.77	0.00	0.00	2.58	6.57	6.69	13.49	14.87	15.11	0.00	0.00	0.00	0.00	7.97	0.00	0.00	9.24
	4	12.52	2.95	0.00	0.00	2.31	2.76	2.88	9.69	11.07	11.30	11.08	11.43	12.35	0.00	9.15	5.51	17.81	10.42
	5	11.71	4.80	1.75	1.65	0.00	2.90	3.02	9.82	11.20	11.44	11.22	17.12	16.59	12.68	8.70	5.06	3.38	9.62
	6	24.06	14.50	12.77	12.71	13.60	0.00	1.95	2.72	4.10	4.34	4.11	4.46	5.39	23.82	23.72	28.46	29.35	21.96
	7	14.84	5.28	3.55	3.49	4.38	10.07	0.00	3.29	4.67	4.90	0.00	5.03	5.95	24.38	24.28	29.03	20.14	12.74
	8	15.01	0.00	0.00	3.66	4.55	2.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	16.56	7.00	5.27	5.21	6.10	3.71	11.91	0.00	0.00	0.43	0.83	1.18	2.10	20.53	20.44	25.18	28.17	14.46
	10	16.77	7.21	5.48	5.42	6.31	3.92	12.12	0.00	1.18	0.00	1.04	1.39	2.31	20.74	20.65	25.39	28.38	14.67
	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	35.99	29.08	0.00	0.00	29.44	6.17	0.00	0.00	3.51	3.64	0.00	0.00	1.59	20.02	19.92	24.67	27.66	33.89
	13	35.22	28.31	0.00	5.85	28.67	4.35	0.00	0.00	1.69	1.83	0.00	1.35	0.00	19.25	19.15	23.90	26.89	33.12
	14	11.51	4.60	0.00	5.67	4.96	5.51	0.00	0.00	2.85	2.98	19.57	2.51	1.98	0.00	0.00	2.01	0.00	0.00
	15	11.12	4.21	0.00	5.28	4.57	15.30	10.98	13.05	12.64	12.78	0.00	12.30	11.77	1.74	0.00	1.40	2.79	9.02
	16	10.21	3.30	0.00	4.37	3.66	14.71	10.07	0.00	12.05	12.19	0.00	11.71	11.18	7.27	0.78	0.00	1.88	8.12
	17	9.21	2.30	0.00	0.00	5.15	8.95	9.07	15.88	19.30	19.43	0.00	18.96	18.43	0.00	10.54	6.90	0.00	7.12
	18	1.44	3.06	10.29	11.20	11.13	16.77	16.90	23.70	25.08	25.32	0.00	0.00	24.41	0.00	16.52	0.00	25.18	0.00

Table F.13: Null alternative delays (in s, per vehicle) at every turn movement in the network.

Turn movement	2020 Delay	2021 Delay	Capacity Delay
RT Ackermann into Piet Retief	42.17	45.49	49.30
LT Ackermann into Piet Retief	42.17	45.49	49.30
LT Ackermann into Koch	0.00	0.00	0.00
RT Ackermann into Koch	0.00	0.00	0.00
LT Jean into Piet Retief	15.31	15.76	16.26
RT Jean into Piet Retief	15.31	15.76	16.26
RT Jean into Koch	9.59	9.64	9.69
LT Jean into Koch	9.59	9.64	9.69
LT Cruse into Piet Retief	36.68	39.12	41.87
RT Cruse into Piet Retief	36.68	39.12	41.87
LT Cruse into Koch	0.00	0.00	0.00
RT Cruse into Koch	0.00	0.00	0.00
LT Vrede into Piet Retief	15.67	16.36	17.16
RT Vrede into Koch	16.38	17.23	18.24
LT Vrede into Koch	16.38	17.23	18.24
LT Skool into Koch	9.82	9.88	9.95
RT Skool into Koch	9.82	9.88	9.95
RT Noordwal-Wes into Piet Retief	104.89	125.27	153.65
LT Noordwal-Wes into Piet Retief	15.89	16.55	17.30
TT Van Reede (die Boord) into Van Reede (node of main node)	0.00	0.00	0.00
LT Van Reede (die Boord) into Strand (node of main node)	0.00	0.00	0.00
LT Barry into Van Reede	30.84	34.34	38.92
RT Barry into Van Reede	130.39	168.76	229.69
LT Bird into Dorp	5.98	6.10	6.23
RT Bird into Dorp	15.52	16.72	18.15
TT Doornbosch into Saffraan (node of main node)	0.00	0.00	0.00
LT Doornbosch into Strand (node of main node)	0.00	0.00	0.00
LT Doornbosch into Van Reede	70.00	0.00	74.00
RT Doornbosch into Van Reede	104.00	0.00	111.00
RT Piet Retief into Skool	10.32	10.50	10.70
TT Piet Retief into Piet Retief at Skool St (N to S)	0.00	0.00	0.00
RT Piet Retief into Jean	0.00	0.00	0.00
TT Piet Retief into Piet Retief at Jean (N to S)	0.00	0.00	0.00
LT Piet Retief into Ackermann	0.00	0.00	0.00
TT Piet Retief into Piet Retief at Ackermann (S to N)	0.00	0.00	0.00
RT Piet Retief into Cruse	0.00	0.00	0.00
TT Piet Retief into Piet Retief at Cruse (N to S)	0.00	0.00	0.00
TT Piet Retief into Piet Retief at Jean (S to N)	0.00	0.00	0.00
LT Piet Retief into Jean	0.00	0.00	0.00
RT Piet Retief into Vrede	6.55	6.69	6.85
TT Piet Retief into Piet Retief at Vrede (N to S)	6.55	6.69	6.85
TT Piet Retief into Piet Retief at Cruse (S to N)	0.00	0.00	0.00
LT Piet Retief into Cruse	0.00	0.00	0.00

TT Koch into Koch at Skool (S to N)	0.00	0.00	0.00
LT Koch into Ackermann	0.00	0.00	0.00
TT Koch into Koch at Ackermann (N to S)	0.00	0.00	0.00
LT Koch into Jean	0.00	0.00	0.00
TT Koch into Koch at Jean (N to S)	0.00	0.00	0.00
RT Koch into Ackermann	0.00	0.00	0.00
TT Koch into Koch at Ackermann (S to N)	0.00	0.00	0.00
LT Koch into Vrede	0.00	0.00	0.00
TT Koch into Koch at Vrede (N to S)	0.00	0.00	0.00
RT Koch into Cruse	0.00	0.00	0.00
TT Koch into Koch at Cruse (S to N)	0.00	0.00	0.00
TT Koch into Koch at Vrede (S to N)	2.95	2.96	2.96
RT Koch into Vrede	2.95	2.96	2.96
TT Koch into Koch at Van Reede (N to S)	0.00	0.00	0.00
RT Koch into Van Reede	0.00	0.00	0.00
TT Koch into Koch at Van Reede (S to N)	17.62	18.43	19.38
LT Koch into Van Reede	17.62	18.43	19.38
LT Piet Retief into Dorp	14.52	14.96	15.45
TT Piet Retief into Mill	16.33	17.68	19.31
RT Piet Retief into Dorp	16.33	17.68	19.31
TT Dorp into Dorp at Bird (E to W)	18.09	19.80	21.92
RT Dorp into Piet Retief	17.13	18.63	20.46
LT Dorp into Mill	12.24	12.91	13.67
TT Dorp into Dorp at Piet Retief / Mill (W to E)	17.13	18.63	20.46
LT Piet Retief into Noordwal-Wes	0.00	0.00	0.00
TT Piet Retief into Piet Retief at Noordwal-Wes (N to S)	0.00	0.00	0.00
RT Piet Retief into Noordwal-Wes	12.13	12.52	12.97
TT Piet Retief into Piet Retief at Noordwal-Wes (S to N)	0.00	0.00	0.00
RT Van Reede into Barry	557.36	723.60	907.83
TT Van Reede into Van Reede at Barry (W to E)	0.00	0.00	0.00
LT Van Reede into Barry	0.00	0.00	0.00
TT Van Reede into Van Reede at Barry (E to W)	0.00	0.00	0.00
LT Van Reede into Doornbosch	12.00	0.00	12.00
TT Van Reede into Van Reede at Doornbosch (W to E)	12.00	0.00	12.00
RT Van Reede into Koch	11.55	11.78	12.03
LT Van Reede into Koch	11.55	11.78	12.03
RT Van Reede into Doornbosch	70.00	0.00	74.00
TT Van Reede into Van Reede at Doornbosch (E to W)	0.00	0.00	0.00
TT Dorp into Dorp at Bird (W to E)	0.00	0.00	0.00
LT Dorp into Piet Retief	8.03	8.27	8.51
TT Dorp into Dorp at Mill (E to W)	10.85	11.33	11.86
RT Dorp into Mill	10.85	11.33	11.86
LT Park into Piet Retief	0.00	0.00	0.00
RT Park into Koch	0.00	0.00	0.00
RT Piet Retief into Park	0.00	0.00	0.00
TT Piet Retief into Piet Retief at Vrede (S to N)	0.00	0.00	0.00

LT Piet Retief into Vrede	0.00	0.00	0.00
TT Piet Retief into Piet Retief at PRG traffic signal (S to N)	3.68	3.81	3.96
RT Piet Retief into Ackermann	0.00	0.00	0.00
TT Piet Retief into Piet Retief at Ackermann (N to S)	0.00	0.00	0.00
TT Piet Retief into Piet Retief at PRG traffic signal (N to S)	3.75	3.89	4.04
LT Piet Retief into Skool	0.00	0.00	0.00
TT Piet Retief into Piet Retief at Skool (S to N)	0.00	0.00	0.00
TT Koch into Koch at Skool (N to S)	0.00	0.00	0.00
TT Koch into Koch at Jean (S to N)	1.37	1.38	1.39
RT Koch into Jean	1.37	1.38	1.39
LT Koch into Cruse	0.00	0.00	0.00
TT Koch into Koch at Cruse (N to S)	0.00	0.00	0.00
TT Strand into Strand at Doornbosch (N to S)	0.00	0.00	0.00
RT Van Reede (die Boord) into Strand S	71.32	73.51	76.07
TT Van Reede into Van Reede at Strand (W to E)	59.16	59.83	60.57
LT Van Reede (die Boord) into Strand N	59.16	59.83	60.57
LT Doornbosch into Strand S	55.82	56.88	58.08
RT Doornbosch into Strand N	55.82	56.88	58.08
TT Doornbosch into Saffraan (E to W)	55.82	56.88	58.08
RT Suidwal W into Piet Retief S at roundabout	42.48	54.07	73.35
LT Suidwal W into Piet Retief N at roundabout	42.48	54.07	73.35
TT Suidwal into Suidwal (W to E)	42.48	54.07	73.35
LT upper Strand N into Dorp E	85.37	97.67	116.49
TT upper Strand into Strand (N to S)	79.22	88.53	102.71
RT Strand N into Van Reede W	80.88	81.66	82.49
TT Strand into Strand at Van Reede (N to S)	265.29	321.95	381.42
LT Strand N into Van Reede E	44.10	44.31	44.54
TT Piet Retief into Piet Retief at Suidwal/roundabout (S to N)	16.55	17.93	19.62
RT Piet Retief S into Suidwal E	16.55	17.93	19.62
RT Trumali into Strand	32.74	32.77	32.80
LT Trumali into Strand	50.06	50.12	50.17
TT Dorp into lower Dorp (E to W)	95.37	103.09	113.60
LT Dorp E into Strand S	88.07	101.49	121.63
LT lower Dorp into Strand N	76.52	84.78	97.23
TT lower Dorp into Dorp (W to E)	76.52	84.78	97.23
RT lower Dorp into Strand S	540.73	604.71	671.29
LT Strand N into Trumali	73.93	76.86	80.39
TT Strand into Strand at Trumali (N to S)	105.79	152.82	205.88
LT Strand S into Van Reede (die Boord)	37.32	37.62	37.93
RT Strand S into Van Reede E	319.79	376.73	436.57
TT Strand into Strand at Van Reede (S to N)	339.58	399.62	461.99
TT Piet Retief into Piet Retief at Suidwal/roundabout (N to S)	32.32	39.58	51.04
LT Piet Retief N into Suidwal E	32.32	39.58	51.04
LT Suidwal E into Piet Retief S	22.96	25.90	29.82
RT Suidwal E into Piet Retief N	22.96	25.90	29.82
RT Strand S into Doornbosch	37.77	37.77	37.77

TT Strand into Strand at Saffraan/Doornbosch (S to N)	191.02	243.32	299.42
LT Strand into Saffraan	39.20	39.25	39.29
TT Van Reede into Van Reede (die Boord) (E to W)	70.79	74.37	79.06
LT Van Reede E into Strand S	125.53	168.65	218.61
RT Van Reede E into Strand N	70.79	74.37	79.06
TT Strand into upper Strand at Dorp (S to N)	42.29	43.22	44.24
RT Strand S into Dorp E	293.23	348.10	406.22
LT Strand S into lower Dorp W	44.78	45.95	47.24
TT Strand into Strand at Trumali (S to N)	63.73	64.72	65.82
RT Strand S into Trumali	501.14	568.69	638.37
TT Saffraan into Doornbosch (W to E)	53.28	53.83	54.41
RT Saffraan into Strand S	53.28	53.83	54.41
LT Saffraan into Strand N	69.62	72.88	77.01
LT Strand N into Doornbosch	33.57	33.87	34.18
TT Strand into Strand at Doornbosch/Saffraan (N to S)	44.88	46.58	48.78
RT Strand N into Saffraan	50.15	50.54	50.95

F.4 NULL-ALTERNATIVE VMT AND VHT

Table F.14: VMT (in km) per O-D pair for the 2020 null-alternative.

2020 VMT 7-8AM		DESTINATIONS																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
ORIGINS	1	0.00	333.41	128.72	43.41	316.98	536.53	1854.41	327.60	479.74	279.78	27.81	327.77	231.92	13.16	603.90	28.68	6.59	84.07
	2	160.37	n.a	n.a	n.a	24.47	2.16	3.74	0.93	11.75	0.47	n.a	30.75	39.93	4.11	98.62	2.78	0.44	16.01
	3	52.44	0.05	n.a	n.a	12.76	1.23	5.40	2.50	0.78	1.78	n.a	n.a	n.a	n.a	11.78	n.a	n.a	0.45
	4	11.57	0.18	n.a	n.a	80.19	17.85	169.59	25.79	27.45	58.10	2.26	1.33	5.42	n.a	67.43	13.75	1.02	1.19
	5	281.48	12.13	n.a	22.89	n.a	12.83	62.05	8.95	63.87	31.08	2.00	116.72	62.61	3.21	115.80	3.98	0.71	26.15
	6	415.36	7.05	n.a	26.98	40.17	n.a	7.15	39.43	76.85	177.86	7.66	1.71	17.48	2.66	29.50	69.64	13.24	39.11
	7	1411.51	23.52	n.a	121.45	150.21	17.59	0.00	2.87	5.33	8.18	n.a	1.95	9.95	0.74	3.86	12.79	65.82	134.11
	8	5.18	n.a	n.a	0.81	0.80	0.24	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
	9	471.35	16.79	n.a	31.06	88.34	49.06	13.60	n.a	n.a	41.07	5.68	0.59	19.87	3.10	31.78	104.86	8.35	41.90
	10	287.73	9.78	n.a	20.11	118.67	33.64	9.99	n.a	14.50	0.00	6.20	0.52	15.26	2.18	99.65	72.90	6.31	27.59
	11	n.a.	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
	12	404.39	27.87	n.a	n.a	72.07	3.21	n.a	n.a	8.56	0.75	n.a	n.a	3.58	0.75	13.16	21.68	2.54	44.82
	13	504.62	36.87	n.a	9.47	84.02	53.43	n.a	n.a	18.02	1.49	n.a	4.13	n.a	0.63	3.17	25.04	2.23	45.75
	14	95.67	2.49	n.a	19.27	21.77	79.60	n.a	n.a	107.95	14.45	23.74	25.43	43.76	n.a	n.a	10.26	n.a	n.a
	15	168.04	8.18	n.a	1.32	18.13	36.33	28.91	8.00	33.57	4.77	n.a	8.40	4.95	140.73	0.00	3.46	0.42	13.68
	16	209.26	11.46	n.a	17.78	31.79	79.21	16.07	n.a	145.07	11.44	n.a	32.90	17.92	1.66	8.26	n.a	0.97	18.23
	17	172.54	5.23	n.a	n.a	2.55	7.96	24.66	5.13	31.48	7.14	n.a	5.32	3.12	n.a	7.14	0.37	0.00	17.62
	18	13.57	5.22	2.06	0.96	4.94	7.38	26.26	9.05	29.34	10.00	n.a	n.a	4.46	n.a	7.23	n.a	0.14	n.a

15349.41

Table F.15: VHT (in min) per O-D pair for the 2020 null-alternative.

2020 VHT 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0.0	789.1	707.6	225.2	1650.1	3122.3	10130.3	2457.9	3081.3	1684.1	180.1	2244.7	1616.7	79.5	3902.9	146.2	80.2	1179.3
	2	491.2	0.0	0.0	0.0	89.0	11.3	17.4	7.8	75.3	2.7	0.0	224.4	300.9	24.5	674.5	10.9	14.0	41.5
	3	260.6	0.2	0.0	0.0	36.9	7.2	26.8	25.3	5.5	11.0	0.0	0.0	0.0	0.0	69.1	0.0	0.0	2.0
	4	55.9	0.7	0.0	0.0	274.8	65.9	528.3	227.9	165.5	308.1	13.9	6.6	28.1	0.0	370.0	47.9	15.9	5.2
	5	1272.6	77.8	11.2	61.2	0.0	34.5	150.0	57.8	318.0	140.0	10.1	983.8	550.2	22.6	1051.9	21.2	4.1	107.2
	6	3312.6	74.4	0.0	403.6	429.8	0.0	33.4	271.2	282.9	554.0	29.1	4.9	56.6	31.8	318.3	866.8	233.0	295.7
	7	6027.8	80.7	0.0	396.5	439.9	77.0	0.0	13.2	17.3	23.4	0.0	5.2	29.7	7.8	37.1	141.8	626.8	533.0
	8	23.6	0.0	0.0	3.2	2.7	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	9	1868.1	53.3	0.0	93.0	265.2	165.0	50.7	0.0	0.0	49.5	19.8	1.0	51.0	58.3	497.8	1907.9	97.3	156.0
	10	1091.8	29.2	0.0	55.8	333.0	100.2	35.3	0.0	35.8	0.0	14.3	0.8	33.8	33.7	1321.7	1129.8	67.1	98.5
	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	12	3550.6	342.3	0.0	0.0	1005.0	12.5	0.0	0.0	40.0	2.6	0.0	0.0	9.2	17.5	242.9	462.7	32.1	377.9
	13	4515.2	472.4	0.0	25.8	1233.3	153.9	0.0	0.0	43.1	2.8	0.0	9.9	0.0	17.3	66.1	601.0	29.4	392.6
	14	311.8	7.8	0.0	57.5	85.9	260.2	0.0	0.0	350.0	36.6	124.7	86.8	143.2	0.0	0.0	26.6	0.0	0.0
	15	597.9	30.6	0.0	4.5	91.7	263.7	124.0	60.2	348.8	39.7	0.0	96.7	63.2	615.9	0.0	11.1	1.2	44.0
	16	675.1	34.6	0.0	51.2	130.0	537.8	63.1	0.0	1369.4	87.5	0.0	341.3	204.4	13.2	13.0	0.0	1.9	52.8
	17	691.3	31.4	0.0	0.0	16.3	45.3	125.2	44.8	256.3	51.5	0.0	45.5	27.8	0.0	66.2	2.1	0.0	61.9
	18	29.7	9.7	10.1	4.5	23.2	39.8	133.3	63.8	178.5	57.1	0.0	0.0	29.4	0.0	43.2	0.0	1.6	0.0

91305.25

Table F.16: VMT (in km) per O-D pair for the 2021 null-alternative.

2021 VMT 7-8AM		DESTINATIONS																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
ORIGINS	1	0.00	343.41	132.58	44.71	326.49	552.62	1910.04	337.43	494.13	288.17	28.64	337.60	238.88	13.55	622.02	29.54	6.79	86.60
	2	165.19	n.a	n.a	n.a	25.20	2.23	3.85	0.96	12.11	0.48	n.a	31.68	41.13	4.23	101.58	2.86	0.45	16.49
	3	54.01	0.05	n.a	n.a	13.14	1.27	5.57	2.58	0.80	1.83	n.a	n.a	n.a	n.a	12.14	n.a	n.a	0.46
	4	11.91	0.18	n.a	n.a	82.59	18.39	174.68	26.56	28.27	59.84	2.33	1.37	5.58	n.a	69.45	14.16	1.05	1.22
	5	289.93	12.49	n.a	23.58	n.a	13.21	63.91	9.22	65.79	32.02	2.06	120.22	64.49	3.31	119.27	4.10	0.73	26.93
	6	427.83	7.27	n.a	27.79	41.38	n.a	7.36	40.61	79.15	183.20	7.89	1.76	18.01	2.74	30.39	71.73	13.64	40.28
	7	1453.85	24.22	n.a	125.10	154.71	18.12	0.00	2.96	5.49	8.43	n.a	2.01	10.25	0.77	3.97	13.17	67.80	138.14
	8	5.33	n.a	n.a	0.83	0.82	0.25	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
	9	485.49	17.29	n.a	31.99	90.99	50.53	14.01	n.a	n.a	42.30	5.85	0.61	20.46	3.19	32.73	108.00	8.60	43.16
	10	296.36	10.07	n.a	20.72	122.23	34.65	10.29	n.a	14.94	0.00	6.39	0.54	15.72	2.25	102.64	75.09	6.50	28.42
	11	n.a.	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
	12	416.52	28.71	n.a	n.a	74.23	3.31	n.a	n.a	8.82	0.77	n.a	n.a	3.69	0.78	13.55	22.33	2.62	46.17
	13	519.76	37.98	n.a	9.75	86.54	55.03	n.a	n.a	18.56	1.54	n.a	4.26	n.a	0.65	3.27	25.79	2.30	47.12
	14	98.54	2.56	n.a	19.84	22.42	81.99	n.a	n.a	111.19	14.88	24.45	26.19	45.08	n.a	n.a	10.56	n.a	n.a
	15	173.08	8.43	n.a	1.36	18.67	37.42	29.78	8.24	34.58	4.91	n.a	8.66	5.09	144.95	0.00	3.57	0.44	14.09
	16	215.54	11.81	n.a	18.32	32.75	81.58	16.55	n.a	149.42	11.79	n.a	33.89	18.45	1.71	8.51	n.a	1.00	18.77
	17	177.71	5.39	n.a	n.a	2.62	8.20	25.40	5.28	32.42	7.36	n.a	5.48	3.22	n.a	7.36	0.38	0.00	18.15
	18	13.98	5.38	2.12	0.99	5.09	7.60	27.05	9.32	30.22	10.30	n.a	n.a	4.59	n.a	7.45	n.a	0.14	n.a

15809.90

Table F.17: VHT (in min) per O-D pair for the 2021 null-alternative.

2021 VHT 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0.0	870.2	832.8	261.9	1935.9	3729.0	12081.8	2969.6	3706.9	2023.1	216.7	2660.7	1918.2	93.8	4618.4	171.4	101.4	1374.6
	2	602.9	0.0	0.0	0.0	96.6	13.4	20.5	9.5	90.6	3.2	0.0	263.7	354.0	28.5	782.9	12.1	18.2	43.8
	3	328.6	0.2	0.0	0.0	39.9	8.8	32.6	31.3	6.7	13.4	0.0	0.0	0.0	0.0	80.2	0.0	0.0	2.3
	4	68.9	0.8	0.0	0.0	298.8	69.7	557.7	268.8	194.0	360.3	16.3	7.7	32.9	0.0	422.6	52.5	20.3	6.1
	5	1583.7	84.5	11.7	63.7	0.0	36.0	156.3	67.6	370.4	162.7	11.7	1160.3	649.7	26.4	1230.6	24.0	4.4	124.3
	6	3942.5	83.7	0.0	458.5	488.7	0.0	37.3	311.6	322.6	628.7	33.2	5.5	65.1	38.3	382.9	1047.8	284.4	340.7
	7	7322.8	86.8	0.0	432.8	484.9	90.4	0.0	15.4	19.9	26.8	0.0	6.0	34.5	9.4	44.6	171.5	787.7	613.3
	8	28.8	0.0	0.0	3.5	3.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	9	2251.9	58.1	0.0	102.6	294.3	181.5	59.0	0.0	0.0	51.4	21.6	1.1	58.3	70.8	603.0	2321.1	117.7	179.2
	10	1314.7	31.8	0.0	61.6	369.7	110.3	41.1	0.0	39.3	0.0	15.7	0.9	38.6	40.8	1599.6	1373.4	81.1	113.1
	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	12	4390.9	412.0	0.0	0.0	1210.0	14.3	0.0	0.0	47.4	3.0	0.0	0.0	10.7	21.3	295.1	564.3	38.8	457.4
	13	5584.5	568.3	0.0	28.5	1484.1	169.7	0.0	0.0	48.5	3.1	0.0	11.0	0.0	21.1	80.3	732.7	35.7	475.0
	14	395.6	8.7	0.0	63.2	96.8	295.8	0.0	0.0	417.2	43.1	148.9	103.8	173.9	0.0	0.0	28.9	0.0	0.0
	15	765.9	34.5	0.0	4.9	104.1	310.6	146.1	71.7	418.7	47.5	0.0	116.1	76.2	722.2	0.0	11.9	1.4	52.3
	16	860.5	37.5	0.0	54.8	142.6	634.2	73.5	0.0	1648.1	104.9	0.0	411.1	246.9	15.8	13.7	0.0	2.1	62.0
	17	900.6	34.0	0.0	0.0	20.5	53.4	147.2	54.0	310.1	62.2	0.0	55.0	33.7	0.0	81.4	2.6	0.0	73.5
	18	30.6	10.5	11.9	5.2	27.2	47.6	159.2	77.2	215.0	68.7	0.0	0.0	34.9	0.0	51.1	0.0	2.0	0.0

109099.81

Table F.18: VMT (in km) per O-D pair for the capacity null-alternative.

Capacity VMT 7-8AM		DESTINATIONS																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
ORIGINS	1	0.00	353.71	136.56	46.05	336.28	569.20	1967.34	347.55	508.96	296.82	29.50	347.73	246.05	13.96	640.68	30.43	6.99	89.19
	2	170.14	n.a	n.a	n.a	25.96	2.30	3.97	0.99	12.47	0.49	n.a	32.63	42.36	4.36	104.63	2.95	0.47	16.99
	3	55.63	0.05	n.a	n.a	13.54	1.31	5.73	2.66	0.83	1.89	n.a	n.a	n.a	n.a	12.50	n.a	n.a	0.47
	4	12.27	0.19	n.a	n.a	85.07	18.94	179.92	27.36	29.12	61.64	2.40	1.42	5.75	n.a	71.54	14.59	1.08	1.26
	5	298.62	12.86	n.a	24.28	n.a	13.61	65.83	9.50	67.76	32.98	2.12	123.83	66.42	3.41	122.85	4.22	0.75	27.74
	6	440.66	7.48	n.a	28.63	42.62	n.a	7.59	41.83	81.53	188.69	8.12	1.81	18.55	2.82	31.30	73.89	14.05	41.49
	7	1497.47	24.95	n.a	128.85	159.35	18.66	0.00	3.05	5.66	8.68	n.a	2.07	10.55	0.79	4.09	13.57	69.83	142.28
	8	5.49	n.a	n.a	0.86	0.85	0.26	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
	9	500.06	17.81	n.a	32.95	93.72	52.04	14.43	n.a	n.a	43.57	6.03	0.62	21.08	3.29	33.71	111.24	8.86	44.45
	10	305.25	10.37	n.a	21.34	125.90	35.69	10.60	n.a	15.38	0.00	6.58	0.56	16.19	2.31	105.72	77.34	6.70	29.27
	11	n.a.	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
	12	429.02	29.57	n.a	n.a	76.46	3.41	n.a	n.a	9.09	0.80	n.a	n.a	3.80	0.80	13.96	23.00	2.70	47.55
	13	535.35	39.12	n.a	10.04	89.14	56.68	n.a	n.a	19.12	1.58	n.a	4.38	n.a	0.67	3.37	26.56	2.36	48.53
	14	101.50	2.64	n.a	20.44	23.09	84.45	n.a	n.a	114.52	15.33	25.18	26.98	46.43	n.a	n.a	10.88	n.a	n.a
	15	178.28	8.68	n.a	1.40	19.23	38.54	30.67	8.48	35.62	5.06	n.a	8.92	5.25	149.30	0.00	3.68	0.45	14.52
	16	222.01	12.16	n.a	18.86	33.73	84.03	17.05	n.a	153.91	12.14	n.a	34.91	19.01	1.76	8.76	n.a	1.03	19.34
	17	183.05	5.55	n.a	n.a	2.70	8.44	26.16	5.44	33.40	7.58	n.a	5.65	3.31	n.a	7.58	0.39	0.00	18.69
	18	14.40	5.54	2.19	1.02	5.24	7.83	27.86	9.60	31.13	10.61	n.a	n.a	4.73	n.a	7.67	n.a	0.15	n.a

16284.19

Table F.19: VHT (in min) per O-D pair for the capacity null-alternative.

Capacity VHT 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0.0	964.8	972.6	302.8	2261.1	4408.0	14265.4	3542.4	4408.8	2401.6	257.5	3155.5	2278.5	110.6	5454.0	200.2	125.7	1585.0
	2	730.9	0.0	0.0	0.0	105.4	15.7	24.0	11.4	107.7	3.8	0.0	311.8	419.5	33.3	914.4	13.5	23.0	46.1
	3	405.1	0.2	0.0	0.0	43.7	10.6	39.2	37.9	8.1	16.1	0.0	0.0	0.0	0.0	93.8	0.0	0.0	2.7
	4	83.4	0.8	0.0	0.0	324.3	74.1	591.8	315.0	226.2	418.6	19.0	9.0	38.5	0.0	486.1	57.8	25.3	6.9
	5	1955.7	93.0	12.2	66.3	0.0	37.5	162.8	78.6	429.0	187.8	13.6	1376.1	772.5	31.1	1447.5	27.4	4.9	144.7
	6	4639.4	93.5	0.0	517.0	552.8	0.0	42.8	366.2	374.0	721.9	38.3	6.3	76.1	46.3	462.6	1271.8	342.7	389.4
	7	8808.9	94.2	0.0	477.7	542.8	105.9	0.0	18.3	23.3	31.0	0.0	6.9	40.5	11.4	53.9	208.3	975.8	703.4
	8	35.0	0.0	0.0	4.0	3.4	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	9	2705.5	64.4	0.0	116.0	335.0	203.2	69.2	0.0	0.0	53.6	24.2	1.2	68.4	86.2	732.9	2832.8	142.9	206.4
	10	1577.8	35.3	0.0	69.5	420.3	123.4	48.2	0.0	44.0	0.0	17.5	1.0	45.1	49.7	1942.0	1674.7	98.5	130.2
	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	12	5414.1	497.9	0.0	0.0	1461.1	16.7	0.0	0.0	57.4	3.6	0.0	0.0	12.5	25.9	358.9	689.1	47.2	554.5
	13	6886.7	686.4	0.0	32.1	1791.3	189.9	0.0	0.0	54.6	3.5	0.0	12.3	0.0	25.7	97.6	894.7	43.3	575.6
	14	495.9	9.9	0.0	70.2	109.7	345.2	0.0	0.0	509.3	51.9	176.5	127.4	220.3	0.0	0.0	31.7	0.0	0.0
	15	966.9	39.5	0.0	5.5	118.9	368.2	171.8	85.8	503.2	56.9	0.0	139.7	92.0	851.8	0.0	13.0	1.6	62.2
	16	1083.2	41.5	0.0	59.5	158.0	753.9	85.7	0.0	1988.0	126.2	0.0	496.4	299.5	18.9	14.4	0.0	2.4	73.1
	17	1153.1	37.8	0.0	0.0	26.8	62.9	172.9	64.6	381.1	76.3	0.0	67.7	41.6	0.0	102.4	3.3	0.0	87.7
	18	31.5	11.5	13.9	6.0	31.8	56.3	188.1	92.2	255.9	81.6	0.0	0.0	41.4	0.0	60.4	0.0	2.5	0.0

130046.64

G. CHAPTER 8 APPENDIX: ESTABLISHING SCHEME SIZE: RESULTS OF THE POTENTIAL-USER AND VEHICLE-TRIP-SAVINGS CALCULATION

Table G.1: Response IDs of the identified SU-student and SU-staff potential bicycle-share users.

SU students		SU staff		
26404	26744	26436	30459	31114
26414	26782	26461	30467	31276
26431	26801	26496	30533	31340
26438	26879	26503	30534	31371
26440	26915	26514	30539	31394
26441	26917	26550	30562	31408
26446	26925	30372	30627	31461
26451	26927	30376	30629	31547
26467	27086	30377	30651	32162
26468	27131	30380	30699	32200
26471	27157	30384	30786	32223
26472	27161	30389	30864	32224
26488	30978	30391	30955	32233
26500	32191	30393	30956	32235
26506	32207	30395	30959	32243
26509	32210	30396	30964	32251
26510	32213	30398	30971	32253
26521	32234	30401	30976	32286
26535	32246	30403	30985	32299
26559	32268	30409	31005	32308
26571	32271	30420	31014	32338
26584	32297	30423	31018	32345
26600	32306	30426	31043	32348
26624	32356	30431	31067	32474
26646	32375	30437	31079	32475
26647	32436	30440	31080	32533
26664	32465	30453	31081	
26697	32466	30455	31098	
26720	32471			
26732	32521			
26741				

H. CHAPTER 9 APPENDIX: CONTEXT-SENSITIVE CONCEPTUAL DESIGN OF THE PROPOSED BICYCLE-SHARING SCHEME FOR STELLENBOSCH

H.1 BICYCLE-FACILITY PROPOSALS OF THE CYCLING PLAN APPLICABLE TO THE STUDY AREA

Table H.1: Bicycle-facility proposals of the Cycling Plan for the study area.

Zone	Street	Section	Length	Cycle route node	Intervention	Code	Priority
A	R44 N/B north view	Paradyskloof to Van Reede	1545.0	A33	Designation of R44 shoulder predominately for cycling excepting vehicle breakdowns / emergencies.	C3	3
A					Develop west-side Class 1 NMT 3m facility connecting Technopark with Die Boord.	NMT	5
A	R44 S/B south view	Van Reede to Paradyskloof	1545.0	A33	Designation of R44 shoulder predominately for cycling excepting vehicle breakdowns / emergencies.	C3	3
A					Resurface & widen existing east-side narrow current walkway.	NMT	2
A	R44 N/B north view	Van Reede to Saffraan	442.0	A35	Designation of R44 shoulder predominately for cycling excepting vehicle breakdowns / emergencies.	C3	3
					Class 1 NMT 3m facility connecting Technopark with Die Boord.	NMT	5
A	R44 S/B south view	Saffraan to Van Reede	442.0	A35	Designation of R44 shoulder predominately for cycling excepting vehicle breakdowns / emergencies.	C3	3
F	Van Reede West east view	R44 to Rhodes North	140.0	F1	Widen & level north-side walkway and cycleway of Van Reede approaching R44.	NMT	2
						C2	2
	Van Reede West west view	R44 to Rhodes North	140.0	F1	Traffic calming on Van Reede is essential. Current 2-way stop at Van Reede/Rokewood/Rhodes North to become 4-way stop & raised box junction with marked NMT crossing for all 4 crossing points. Traffic calming speed bumps necessary for all approaches.	NMT	1/2
S	Doornbosch	Strand to turn in road	220.0	S2	Street too narrow for Class 3 cycleway. Footpath along Eikestad fence too narrow for walking and cycling. Calmed road preferred solution otherwise wide NMT path on south-side Markotter will prevent parking, only possible if parking is formalised & reduced/woonerf.	NMT 2 / TC	4/5
S	Doornbosch	Turn in road to walkway	248.7	S3	Space for cycling only possible if reduce parking for cars. Some limited opportunity for widening pavements. Calmed route preferred solution otherwise, some limited opportunity for widening pavements around school/woonerf.	NMT / TC	4/5
S	Doornbosch	Walkway to Van Reede	236.0	S4	Space for cycling only possible if reduce parking for cars. Some limited opportunity for widening pavements around school. Further option to remove & replant trees on the east-side fence line and create Class 2 cycleway.	C3	4/5
S	Van Reede	Strand to Koch	583.0	S5	Resurface Class 1 NMT route (separate cycle & walk with paint)	NMT 1 / C1	3
S	Koch	Vrede to Jean	580.4	S9	Widen west-side pavement where possible, mark for pedestrian - existing path (green) and cycling (wider path - red).	NMT / C2	2/3
S	Suidwal/Piet Retief	Van Reede intersection	205.8	S10	Extend NMT across Park to Piet Retief.	NMT	4/5
S				S12	Widen west-side pavement where possible, mark for pedestrians - existing path (green) & cycling (wider path - red).	NMT	3
S	Piet Retief	Park to Suidwal	824.9	S15	Short term: widen existing NMT path to fence line. Mark centre line.	NMT	2
					Medium term: include Class 3, 1.2m-1.5m cycleway on both sides in current road.	C3	3
					Long term: delineate cycleway (with separators).	C2	4
S	Piet Retief	Suidwal to Noordwal-Wes		S16	Build bridge for walking and cycling next to road bridge.	C2	4
S	Piet Retief	Noordwal-Wes to Dorp	231.8	S17	Remove kerbside parking (ample capacity in Transvalia / Stelkor car-park at rear).	C3	3/4
S	Suidwal	Paul Roos Gymnasium	81.6	S38	Widen pathway on south-side & remove obstacles, also put in crossing point. Extend measures to create full fledged recreational route.	NMT	2
S	Suidwal	Paul Roos Gymnasium	889.0	S39	Further traffic calming - possible demonstration route for shared-space roadway. Demonstration for "sharrows" to give cycling priority of carriageway use over cars.	TC	2
S	Suidwal	Maties Soccer and Tennis	377.0	S41	No current south-side path between parking and athletics stadium. Essential to construct NMT.	NMT	2
S	Die Laan	Suidwal to Van Riebeek	244.6	S43	Traffic calming measure. Possible future option to remove parking & provide Class 3 cycleway.	TC / C3	3/5

S	Pastorie	Ryneveld to Helderberg	682.0	S45	Formalise off-road trail (laterite). Will require removal of some parking opportunity.	T1	3
S	Helderberg	Die Laan to Piet Retief	368.5	S46	Off-street riverside trail.	T1	3
S	Victoria	Bosman to Andringa	975.1	S78	Currently calmed street, shared space with no kerbside parking. Some cycling occurs on north side widened pathway. Short-term option to mark as Class 3 cycleway (woonerf).	C3	1
S	Ryneveld	Plein to Victoria	300.0	S80	Shared space and traffic calming. Option between Ryneveld and Plein to cycle in both directions (longer term).	C2	4/5
S	Bosman	Victoria to Merriman	314.7	S91	Important cycle link. Shared space. Further traffic calming as necessary.	TC	4
S	Bosman	Merriman to Banghoek		S92	Important cycle link. Shared space. Further traffic calming as necessary.	TC	4
S	Bosman	Victoria to Van Riebeek	314.8	S92a	Important cycle link. Shared space. Further traffic calming as necessary.	TC	4
					Long term options (may not be necessary or feasible): (1) removing east-side parking and provide class 3 cycleway, (2) rmeoving east-side parking and provide Class 2 bidirectional cycleway.	C3	4/5
S	Banghoek	Bosman to Joubert	287.0	S97	Important route. Shared space, further traffic calming as necessary.	TC	4

I. CHAPTER 10 APPENDIX: BICYCLE-SHARING COST ANALYSIS

I.1 BICYCLE MAINTENANCE COST QUOTES

Table I.1: Flandria Cycle minimum labour tariffs for bicycle repairs.

WORKSHOP MINIMUM LABOUR TARIFF	PRICE (ZAR)
Bike: check	200-550
Bike: rebuild	550
Brake: tune/disc	100
Brake: tune/V brake	60
Brake blocks: replace MTB	75
Brake blocks: replace ROAD	50
Brake cable: replace	40-60
Brakes: bleed incl. oil/per brake	150
Cluster: chain replace	135
Wash/lube	85
Fit: OWN accessories, saddle, bar ends, etc.	60
Fit: OWN cluster, chain, jockey	150-250
Fit: OWN tubeless tyre excl. sealant	50
Fit: OWN tyre, tube, slime	45
Fit: permatube	120 (steel rim only)
Fit: sealant in tube	30
Fit: sealant MTB	35
Fit: tube	30
Fit: tubular ROAD incl. glue	120
Gear blade or B/B: replace	100
Gear cable: replace	90-140
Gears: tune	100
Heater: check/service	120
Service: major/hubs/freebody/straight/lube	550
Service: ordinary/wash/lube	295
Service: small	220
Wheel: hub service front	100
Wheel: hub service rear	100
Wheel: rebuild	230
Wheel: replace axle	100
Wheel: replace bearings	100-140
Wheel straight	120

J. CHAPTER 12 APPENDIX: BICYCLE-SHARING BENEFIT ANALYSIS

J.1 2020 O-D MATRICES FOR THE BICYCLE-SHARING ALTERNATIVE

Table J.1 2020 O-D matrix for the B2B5 bicycle-sharing-alternative modifications.

B2 and B5

O/D MATRIX 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0	238	83	24	179	237	762	137	161	87	9	116	0	5	74	14	5	130
	2	113	0	0	0	37	2	3	1	6	0	0	18	25	3	107	3	1	11
	3	34	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0
	4	6	0	0	0	133	25	193	31	19	35	2	1	3	0	50	10	1	1
	5	157	18	7	38	0	12	51	8	36	15	1	76	44	2	157	5	1	14
	6	182	6	0	38	38	0	21	127	86	157	9	1	13	2	18	42	11	17
	7	560	17	0	129	117	10	0	5	5	6	0	1	6	0	2	7	46	52
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	9	154	9	0	21	52	52	5	0	20	118	27	1	31	4	34	106	5	13
	10	89	5	0	12	63	30	4	0	35	0	16	1	18	2	89	62	3	8
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	142	16	0	0	47	3	0	0	15	1	0	0	7	1	17	26	2	15
	13	0	23	0	5	59	41	0	0	30	2	0	9	0	1	5	35	2	16
	14	0	2	0	12	21	59	0	0	169	16	9	48	5	0	0	15	0	0
	15	0	9	0	1	25	23	15	6	38	4	0	11	7	319	0	9	1	7
	16	100	12	0	13	41	48	8	0	156	10	0	40	25	2	17	0	1	8
	17	118	15	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12
	18	21	4	1	1	3	3	10	4	10	3	0	0	2	0	3	0	0	0

Table J.2 2020 O-D matrix for the B2M7 and M1B5 bicycle-sharing-alternative modifications.

B2 and M7
M1 and B5

O/D MATRIX 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0	238	83	24	179	237	762	137	161	87	9	116	0	5	150	14	5	130
	2	113	0	0	0	37	2	3	1	6	0	0	18	25	3	107	3	1	11
	3	34	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0
	4	6	0	0	0	133	25	193	31	19	35	2	1	3	0	50	10	1	1
	5	157	18	7	38	0	12	51	8	36	15	1	76	44	2	157	5	1	14
	6	182	6	0	38	38	0	21	127	86	157	9	1	13	2	18	42	11	17
	7	560	17	0	129	117	10	0	5	5	6	0	1	6	0	2	7	46	52
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	9	154	9	0	21	52	52	5	0	20	118	27	1	31	4	34	106	5	13
	10	89	5	0	12	63	30	4	0	35	0	16	1	18	2	89	62	3	8
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	142	16	0	0	47	3	0	0	15	1	0	0	7	1	17	26	2	15
	13	75	23	0	5	59	41	0	0	30	2	0	9	0	1	5	35	2	16
	14	0	2	0	12	21	59	0	0	169	16	9	48	81	0	0	15	0	0
	15	0	9	0	1	25	23	15	6	38	4	0	11	7	395	0	9	1	7
	16	100	12	0	13	41	48	8	0	156	10	0	40	25	2	17	0	1	8
	17	118	15	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12
	18	21	4	1	1	3	3	10	4	10	3	0	0	2	0	3	0	0	0

Table J.3 2020 O-D matrix for the M1M7 bicycle-sharing-alternative modifications.

M1 and M7

O/D MATRIX 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0	238	83	24	179	237	762	137	161	87	9	116	34	5	174	14	5	130
	2	113	0	0	0	37	2	3	1	6	0	0	18	25	3	107	3	1	11
	3	34	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0
	4	6	0	0	0	133	25	193	31	19	35	2	1	3	0	50	10	1	1
	5	157	18	7	38	0	12	51	8	36	15	1	76	44	2	157	5	1	14
	6	182	6	0	38	38	0	21	127	86	157	9	1	13	2	18	42	11	17
	7	560	17	0	129	117	10	0	5	5	6	0	1	6	0	2	7	46	52
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	9	154	9	0	21	52	52	5	0	20	118	27	1	31	4	34	106	5	13
	10	89	5	0	12	63	30	4	0	35	0	16	1	18	2	89	62	3	8
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	142	16	0	0	47	3	0	0	15	1	0	0	7	1	17	26	2	15
	13	133	23	0	5	59	41	0	0	30	2	0	9	0	1	5	35	2	16
	14	0	2	0	12	21	59	0	0	169	16	9	48	105	0	0	15	0	0
	15	0	9	0	1	25	23	15	6	38	4	0	11	7	419	0	9	1	7
	16	100	12	0	13	41	48	8	0	156	10	0	40	25	2	17	0	1	8
	17	118	15	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12
	18	21	4	1	1	3	3	10	4	10	3	0	0	2	0	3	0	0	0

Table J.4 2020 O-D matrix for the B2M10 and M4B5 bicycle-sharing-alternative modifications.

B2 and M10
M4 and B5

O/D MATRIX 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0	238	83	24	179	237	762	137	161	87	9	116	54	5	174	14	5	130
	2	113	0	0	0	37	2	3	1	6	0	0	18	25	3	107	3	1	11
	3	34	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0
	4	6	0	0	0	133	25	193	31	19	35	2	1	3	0	50	10	1	1
	5	157	18	7	38	0	12	51	8	36	15	1	76	44	2	157	5	1	14
	6	182	6	0	38	38	0	21	127	86	157	9	1	13	2	18	42	11	17
	7	560	17	0	129	117	10	0	5	5	6	0	1	6	0	2	7	46	52
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	9	154	9	0	21	52	52	5	0	20	118	27	1	31	4	34	106	5	13
	10	89	5	0	12	63	30	4	0	35	0	16	1	18	2	89	62	3	8
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	142	16	0	0	47	3	0	0	15	1	0	0	7	1	17	26	2	15
	13	153	23	0	5	59	41	0	0	30	2	0	9	0	1	5	35	2	16
	14	0	2	0	12	21	59	0	0	169	16	9	48	105	0	0	15	0	0
	15	0	9	0	1	25	23	15	6	38	4	0	11	7	419	0	9	1	7
	16	100	12	0	13	41	48	8	0	156	10	0	40	25	2	17	0	1	8
	17	118	15	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12
	18	21	4	1	1	3	3	10	4	10	3	0	0	2	0	3	0	0	0

Table J.5 2020 O-D matrix for the M1M10 and M4M7 bicycle-sharing-alternative modifications.

M1 and M10
M4 and M7

O/D MATRIX 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0	238	83	24	179	237	762	137	161	87	9	116	85	5	181	14	5	130
	2	113	0	0	0	37	2	3	1	6	0	0	18	25	3	107	3	1	11
	3	34	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0
	4	6	0	0	0	133	25	193	31	19	35	2	1	3	0	50	10	1	1
	5	157	18	7	38	0	12	51	8	36	15	1	76	44	2	157	5	1	14
	6	182	6	0	38	38	0	21	127	86	157	9	1	13	2	18	42	11	17
	7	560	17	0	129	117	10	0	5	5	6	0	1	6	0	2	7	46	52
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	9	154	9	0	21	52	52	5	0	20	118	27	1	31	4	34	106	5	13
	10	89	5	0	12	63	30	4	0	35	0	16	1	18	2	89	62	3	8
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	142	16	0	0	47	3	0	0	15	1	0	0	7	1	17	26	2	15
	13	184	23	0	5	59	41	0	0	30	2	0	9	0	1	5	35	2	16
	14	7	2	0	12	21	59	0	0	169	16	9	48	105	0	0	15	0	0
	15	0	9	0	1	25	23	15	6	38	4	0	11	7	426	0	9	1	7
	16	100	12	0	13	41	48	8	0	156	10	0	40	25	2	17	0	1	8
	17	118	15	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12
	18	21	4	1	1	3	3	10	4	10	3	0	0	2	0	3	0	0	0

Table J.6 2020 O-D matrix for the B2B3B5B6 bicycle-sharing-alternative modifications.

B2B3 and B5B6

O/D MATRIX 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0	717	83	24	179	237	610	137	70	0	9	0	0	5	41	14	5	130
	2	113	0	0	0	37	2	3	1	6	0	0	18	11	3	107	3	1	11
	3	34	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0
	4	6	0	0	0	133	25	193	31	19	35	2	1	3	0	50	10	1	1
	5	157	18	7	38	0	12	51	8	36	15	1	76	44	2	157	5	1	14
	6	182	6	0	38	38	0	21	127	86	157	9	1	13	2	18	42	11	17
	7	560	17	0	129	117	10	0	5	5	6	0	1	6	0	2	7	46	52
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	9	154	9	0	21	52	52	5	0	20	118	27	1	31	4	34	106	5	13
	10	89	5	0	12	63	30	4	0	35	0	16	1	18	2	89	62	3	8
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	142	16	0	0	47	3	0	0	15	1	0	0	7	1	17	26	2	15
	13	0	23	0	5	59	41	0	0	30	2	0	9	0	1	5	35	2	16
	14	0	2	0	12	21	59	0	0	169	16	9	48	5	0	0	15	0	0
	15	0	9	0	1	25	23	15	6	5	4	0	11	7	319	0	9	1	7
	16	100	12	0	13	41	48	8	0	156	10	0	40	25	2	17	0	1	8
	17	118	15	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12
	18	21	4	1	1	3	3	10	4	10	3	0	0	2	0	3	0	0	0

Table J.7 2020 O-D matrix for the B2B3M7M8 and M1M2B5B6 bicycle-sharing-alternative modifications.

B2B3 and M7M8 M1M2 and B5B6																			
O/D MATRIX 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0	608	83	24	179	237	648	137	114	0	9	18	0	5	126	14	5	130
	2	113	0	0	0	37	2	3	1	6	0	0	18	25	3	107	3	1	11
	3	34	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0
	4	6	0	0	0	133	25	193	31	19	35	2	1	3	0	50	10	1	1
	5	157	18	7	38	0	12	51	8	36	15	1	76	44	2	157	5	1	14
	6	182	6	0	38	38	0	21	127	86	157	9	1	13	2	18	42	11	17
	7	560	17	0	129	117	10	0	5	5	6	0	1	6	0	2	7	46	52
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	9	154	9	0	21	52	52	5	0	20	118	27	1	31	4	34	106	5	13
	10	89	5	0	12	63	30	4	0	35	0	16	1	18	2	89	62	3	8
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	142	16	0	0	47	3	0	0	15	1	0	0	7	1	17	26	2	15
	13	75	23	0	5	59	41	0	0	30	2	0	9	0	1	5	35	2	16
	14	0	2	0	12	21	59	0	0	169	16	9	48	81	0	0	15	0	0
	15	0	9	0	1	25	23	15	6	14	4	0	11	7	395	0	9	1	7
	16	100	12	0	13	41	48	8	0	156	10	0	40	25	2	17	0	1	8
	17	118	15	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12
	18	21	4	1	1	3	3	10	4	10	3	0	0	2	0	3	0	0	0

Table J.8 2020 O-D matrix for the M1M2M7M8 bicycle-sharing-alternative modifications.

M1M2 and M7M8

O/D MATRIX 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0	515	83	24	179	237	677	137	148	0	9	76	0	5	156	14	5	130
	2	113	0	0	0	37	2	3	1	6	0	0	18	25	3	107	3	1	11
	3	34	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0
	4	6	0	0	0	133	25	193	31	19	35	2	1	3	0	50	10	1	1
	5	157	18	7	38	0	12	51	8	36	15	1	76	44	2	157	5	1	14
	6	182	6	0	38	38	0	21	127	86	157	9	1	13	2	18	42	11	17
	7	560	17	0	129	117	10	0	5	5	6	0	1	6	0	2	7	46	52
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	9	154	9	0	21	52	52	5	0	20	118	27	1	31	4	34	106	5	13
	10	89	5	0	12	63	30	4	0	35	0	16	1	18	2	89	62	3	8
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	142	16	0	0	47	3	0	0	15	1	0	0	7	1	17	26	2	15
	13	133	23	0	5	59	41	0	0	30	2	0	9	0	1	5	35	2	16
	14	0	2	0	12	21	59	0	0	169	16	9	48	105	0	0	15	0	0
	15	0	9	0	1	25	23	15	6	20	4	0	11	7	419	0	9	1	7
	16	100	12	0	13	41	48	8	0	156	10	0	40	25	2	17	0	1	8
	17	118	15	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12
	18	21	4	1	1	3	3	10	4	10	3	0	0	2	0	3	0	0	0

Table J.9 2020 O-D matrix for the B2B3M10M11 and M4M5B5B6 bicycle-sharing-alternative modifications.

B2B3 and M10M11
M4M5 and B5B6

O/D MATRIX 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0	485	83	24	179	237	686	137	159	0	9	83	21	5	158	14	5	130
	2	113	0	0	0	37	2	3	1	6	0	0	18	25	3	107	3	1	11
	3	34	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0
	4	6	0	0	0	133	25	193	31	19	35	2	1	3	0	50	10	1	1
	5	157	18	7	38	0	12	51	8	36	15	1	76	44	2	157	5	1	14
	6	182	6	0	38	38	0	21	127	86	157	9	1	13	2	18	42	11	17
	7	560	17	0	129	117	10	0	5	5	6	0	1	6	0	2	7	46	52
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	9	154	9	0	21	52	52	5	0	20	118	27	1	31	4	34	106	5	13
	10	89	5	0	12	63	30	4	0	35	0	16	1	18	2	89	62	3	8
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	142	16	0	0	47	3	0	0	15	1	0	0	7	1	17	26	2	15
	13	153	23	0	5	59	41	0	0	30	2	0	9	0	1	5	35	2	16
	14	0	2	0	12	21	59	0	0	169	16	9	48	105	0	0	15	0	0
	15	0	9	0	1	25	23	15	6	22	4	0	11	7	419	0	9	1	7
	16	100	12	0	13	41	48	8	0	156	10	0	40	25	2	17	0	1	8
	17	118	15	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12
	18	21	4	1	1	3	3	10	4	10	3	0	0	2	0	3	0	0	0

Table J.10 2020 O-D matrix for the M1M2M10M11 and M4M5M7M8 bicycle-sharing-alternative modifications.

M1M2 and M10M11
M4M5 and M7M8

O/D MATRIX 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0	422	83	24	179	237	705	137	161	20	9	92	61	5	169	14	5	130
	2	113	0	0	0	37	2	3	1	6	0	0	18	25	3	107	3	1	11
	3	34	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0
	4	6	0	0	0	133	25	193	31	19	35	2	1	3	0	50	10	1	1
	5	157	18	7	38	0	12	51	8	36	15	1	76	44	2	157	5	1	14
	6	182	6	0	38	38	0	21	127	86	157	9	1	13	2	18	42	11	17
	7	560	17	0	129	117	10	0	5	5	6	0	1	6	0	2	7	46	52
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	9	154	9	0	21	52	52	5	0	20	118	27	1	31	4	34	106	5	13
	10	89	5	0	12	63	30	4	0	35	0	16	1	18	2	89	62	3	8
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	142	16	0	0	47	3	0	0	15	1	0	0	7	1	17	26	2	15
	13	184	23	0	5	59	41	0	0	30	2	0	9	0	1	5	35	2	16
	14	7	2	0	12	21	59	0	0	169	16	9	48	105	0	0	15	0	0
	15	0	9	0	1	25	23	15	6	26	4	0	11	7	426	0	9	1	7
	16	100	12	0	13	41	48	8	0	156	10	0	40	25	2	17	0	1	8
	17	118	15	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12
	18	21	4	1	1	3	3	10	4	10	3	0	0	2	0	3	0	0	0

Table J.11 2020 O-D matrix for the B2B3B4B5B6B7 bicycle-sharing-alternative modifications.

B2B3B4 and B5B6B7

O/D MATRIX 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0	884	83	24	179	237	552	137	0	0	9	0	0	5	0	14	5	130
	2	113	0	0	0	37	2	3	1	6	0	0	0	0	3	42	3	1	11
	3	34	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0
	4	6	0	0	0	133	25	193	31	19	35	2	1	3	0	50	10	1	1
	5	157	18	7	38	0	12	51	8	36	15	1	76	44	2	157	5	1	14
	6	182	6	0	38	38	0	21	127	86	157	9	1	13	2	18	42	11	17
	7	560	17	0	129	117	10	0	5	5	6	0	1	6	0	2	7	46	52
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	9	154	9	0	21	52	52	5	0	20	118	27	1	31	4	34	106	5	13
	10	89	5	0	12	63	30	4	0	35	0	16	1	18	2	89	62	3	8
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	142	16	0	0	47	3	0	0	15	1	0	0	7	1	17	26	2	15
	13	0	23	0	5	59	41	0	0	30	2	0	9	0	1	5	35	2	16
	14	0	2	0	12	21	59	0	0	123	16	9	11	0	0	0	15	0	0
	15	0	9	0	1	25	23	15	6	5	4	0	0	0	231	0	9	1	7
	16	100	12	0	13	41	48	8	0	156	10	0	40	25	2	17	0	1	8
	17	118	15	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12
	18	21	4	1	1	3	3	10	4	10	3	0	0	2	0	3	0	0	0

Table J.12 2020 O-D matrix for the B2B3B4M7M8M9 and M1M2M3B5B6B7 bicycle-sharing-alternative modifications.

B2B3B4 and M7M8M9
M1M2M3 and B5B6B7

O/D MATRIX 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0	784	83	24	179	237	605	137	61	0	9	0	0	5	91	14	5	130
	2	113	0	0	0	37	2	3	1	6	0	0	0	0	3	101	3	1	11
	3	34	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0
	4	6	0	0	0	133	25	193	31	19	35	2	1	3	0	50	10	1	1
	5	157	18	7	38	0	12	51	8	36	15	1	76	44	2	157	5	1	14
	6	182	6	0	38	38	0	21	127	86	157	9	1	13	2	18	42	11	17
	7	560	17	0	129	117	10	0	5	5	6	0	1	6	0	2	7	46	52
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	9	154	9	0	21	52	52	5	0	20	118	27	1	31	4	34	106	5	13
	10	89	5	0	12	63	30	4	0	35	0	16	1	18	2	89	62	3	8
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	142	16	0	0	47	3	0	0	15	1	0	0	7	1	17	26	2	15
	13	75	23	0	5	59	41	0	0	30	2	0	9	0	1	5	35	2	16
	14	0	2	0	12	21	59	0	0	158	16	9	48	81	0	0	15	0	0
	15	0	9	0	1	25	23	15	6	0	4	0	11	1	384	0	9	1	7
	16	100	12	0	13	41	48	8	0	156	10	0	40	25	2	17	0	1	8
	17	118	15	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12
	18	21	4	1	1	3	3	10	4	10	3	0	0	2	0	3	0	0	0

Table J.13 2020 O-D matrix for the M1M2M3M7M8M9 bicycle-sharing-alternative modifications.

M1M2M3 and M7M8M9

O/D MATRIX 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0	662	83	24	179	237	645	137	108	0	9	26	0	5	130	14	5	130
	2	113	0	0	0	37	2	3	1	6	0	0	18	25	3	107	3	1	11
	3	34	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0
	4	6	0	0	0	133	25	193	31	19	35	2	1	3	0	50	10	1	1
	5	157	18	7	38	0	12	51	8	36	15	1	76	44	2	157	5	1	14
	6	182	6	0	38	38	0	21	127	86	157	9	1	13	2	18	42	11	17
	7	560	17	0	129	117	10	0	5	5	6	0	1	6	0	2	7	46	52
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	9	154	9	0	21	52	52	5	0	20	118	27	1	31	4	34	106	5	13
	10	89	5	0	12	63	30	4	0	35	0	16	1	18	2	89	62	3	8
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	142	16	0	0	47	3	0	0	15	1	0	0	7	1	17	26	2	15
	13	133	23	0	5	59	41	0	0	30	2	0	9	0	1	5	35	2	16
	14	0	2	0	12	21	59	0	0	163	16	9	48	105	0	0	15	0	0
	15	0	9	0	1	25	23	15	6	0	4	0	11	7	413	0	9	1	7
	16	100	12	0	13	41	48	8	0	156	10	0	40	25	2	17	0	1	8
	17	118	15	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12
	18	21	4	1	1	3	3	10	4	10	3	0	0	2	0	3	0	0	0

Table J.14 2020 O-D matrix for the B2B3B4M10M11M12 and M4M5M6B5B6B7 bicycle-sharing-alternative modifications.

B2B3B4 and M10M11M12
M4M5M6 and B5B6B7

O/D MATRIX 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0	616	83	24	179	237	657	137	124	0	9	59	0	5	136	14	5	130
	2	113	0	0	0	37	2	3	1	6	0	0	18	25	3	107	3	1	11
	3	34	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0
	4	6	0	0	0	133	25	193	31	19	35	2	1	3	0	50	10	1	1
	5	157	18	7	38	0	12	51	8	36	15	1	76	44	2	157	5	1	14
	6	182	6	0	38	38	0	21	127	86	157	9	1	13	2	18	42	11	17
	7	560	17	0	129	117	10	0	5	5	6	0	1	6	0	2	7	46	52
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	9	154	9	0	21	52	52	5	0	20	118	27	1	31	4	34	106	5	13
	10	89	5	0	12	63	30	4	0	35	0	16	1	18	2	89	62	3	8
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	142	16	0	0	47	3	0	0	15	1	0	0	7	1	17	26	2	15
	13	153	23	0	5	59	41	0	0	30	2	0	9	0	1	5	35	2	16
	14	0	2	0	12	21	59	0	0	169	16	9	48	105	0	0	15	0	0
	15	0	9	0	1	25	23	15	6	0	4	0	11	7	419	0	9	1	7
	16	100	12	0	13	41	48	8	0	156	10	0	40	25	2	17	0	1	8
	17	118	15	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12
	18	21	4	1	1	3	3	10	4	10	3	0	0	2	0	3	0	0	0

Table J.15 2020 O-D matrix for the M1M2M3M10M11M12 and M4M5M6M7M8M9 bicycle-sharing-alternative modifications.

M1M2M3 and M10M11M12
M4M5M6 and M7M8M9

O/D MATRIX 7-8AM		DESTINATIONS																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
ORIGINS	**1**	0	519	83	24	179	237	684	137	155	0	9	75	45	5	152	14	5	130
	2	113	0	0	0	37	2	3	1	6	0	0	18	25	3	107	3	1	11
	3	34	0	0	0	16	2	6	3	1	1	0	0	0	0	11	0	0	0
	4	6	0	0	0	133	25	193	31	19	35	2	1	3	0	50	10	1	1
	5	157	18	7	38	0	12	51	8	36	15	1	76	44	2	157	5	1	14
	6	182	6	0	38	38	0	21	127	86	157	9	1	13	2	18	42	11	17
	7	560	17	0	129	117	10	0	5	5	6	0	1	6	0	2	7	46	52
	8	2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	9	154	9	0	21	52	52	5	0	20	118	27	1	31	4	34	106	5	13
	10	89	5	0	12	63	30	4	0	35	0	16	1	18	2	89	62	3	8
	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	142	16	0	0	47	3	0	0	15	1	0	0	7	1	17	26	2	15
	13	184	23	0	5	59	41	0	0	30	2	0	9	0	1	5	35	2	16
	14	7	2	0	12	21	59	0	0	169	16	9	48	105	0	0	15	0	0
	15	0	9	0	1	25	23	15	6	9	4	0	11	7	426	0	9	1	7
	16	100	12	0	13	41	48	8	0	156	10	0	40	25	2	17	0	1	8
	17	118	15	0	0	5	7	18	4	19	4	0	3	2	0	9	0	0	12
	18	21	4	1	1	3	3	10	4	10	3	0	0	2	0	3	0	0	0

J.2 HEALTH BENEFITS: HEAT FOR CYCLING RESULTS FOR THE BICYCLE-SHARING ALTERNATIVE

HEAT estimate

04 December 2015 - 21:14 (v2.3)

Reduced mortality as a result of changes in cycling behaviour

The cycling data you have entered corresponds to an average of 83.33 hours per person per year.

This level of cycling provides an estimated protective benefit of: 10 % (compared to persons not cycling regularly)

From the data you have entered, the number of individuals who benefit from this level of cycling is: 637

Out of this many individuals, the number who would be expected to die if they were not cycling regularly would be: 1.01

The number of deaths per year that are prevented by this level of cycling is: less than 1

Economic value of cycling

Currency: EUR, rounded to 1000

The value of statistical life applied is: 1,000,000 EUR	
The annual benefit of this level of cycling, per year, is:	97,000 EUR
The total benefits accumulated over 15 years are:	1,461,000 EUR
When future benefits are discounted by 3 % per year:	
the current value of the average annual benefit, averaged across 15 years is:	78,000 EUR
the current value of the total benefits accumulated over 15 years is:	1,163,000 EUR

Please bear in mind that HEAT does not calculate risk reductions for individual persons but an average across the population under study. The results should not be misunderstood to represent individual risk reductions. Also note that the VSL not assign a value to the life of one particular person but refers to an average value of a “statistical life”.

It is important to remember that many of the variables used within this HEAT calculation are estimates and therefore liable to some degree of error.

You are reminded that the HEAT tools provide you with an approximation of the level of health benefits. To get a better sense for the possible range of the results, you are strongly advised to rerun the model , entering slightly different values for variables where you have provided a “best guess”, such as entering high and low estimates for such variables.

HEAT estimate

04 December 2015 - 21:16 (v2.3)

Reduced mortality as a result of changes in cycling behaviour

The cycling data you have entered corresponds to an average of 83.33 hours per person per year.

This level of cycling provides an estimated protective benefit of: 10 % (compared to persons not cycling regularly)

From the data you have entered, the number of individuals who benefit from this level of cycling is: 478

Out of this many individuals, the number who would be expected to die if they were not cycling regularly would be: 0.76

The number of deaths per year that are prevented by this level of cycling is: less than 1

Economic value of cycling

Currency: EUR, rounded to 1000

The value of statistical life applied is: 1,000,000 EUR	
The annual benefit of this level of cycling, per year, is:	73,000 EUR
The total benefits accumulated over 15 years are:	1,096,000 EUR
When future benefits are discounted by 3 % per year:	
the current value of the average annual benefit, averaged across 15 years is:	58,000 EUR
the current value of the total benefits accumulated over 15 years is:	873,000 EUR

Please bear in mind that HEAT does not calculate risk reductions for individual persons but an average across the population under study. The results should not be misunderstood to represent individual risk reductions. Also note that the VSL not assign a value to the life of one particular person but refers to an average value of a “statistical life”.

It is important to remember that many of the variables used within this HEAT calculation are estimates and therefore liable to some degree of error.

You are reminded that the HEAT tools provide you with an approximation of the level of health benefits. To get a better sense for the possible range of the results, you are strongly advised to rerun the model , entering slightly different values for variables where you have provided a “best guess”, such as entering high and low estimates for such variables.

HEAT estimate

04 December 2015 - 21:15 (v2.3)

Reduced mortality as a result of changes in cycling behaviour

The cycling data you have entered corresponds to an average of 83.33 hours per person per year.

This level of cycling provides an estimated protective benefit of: 10 % (compared to persons not cycling regularly)

From the data you have entered, the number of individuals who benefit from this level of cycling is: 424

Out of this many individuals, the number who would be expected to die if they were not cycling regularly would be: 0.67

The number of deaths per year that are prevented by this level of cycling is: less than 1

Economic value of cycling

Currency: EUR, rounded to 1000

The value of statistical life applied is: 1,000,000 EUR	
The annual benefit of this level of cycling, per year, is:	65,000 EUR
The total benefits accumulated over 15 years are:	973,000 EUR
When future benefits are discounted by 3 % per year:	
the current value of the average annual benefit, averaged across 15 years is:	52,000 EUR
the current value of the total benefits accumulated over 15 years is:	774,000 EUR

Please bear in mind that HEAT does not calculate risk reductions for individual persons but an average across the population under study. The results should not be misunderstood to represent individual risk reductions. Also note that the VSL not assign a value to the life of one particular person but refers to an average value of a “statistical life”.

It is important to remember that many of the variables used within this HEAT calculation are estimates and therefore liable to some degree of error.

You are reminded that the HEAT tools provide you with an approximation of the level of health benefits. To get a better sense for the possible range of the results, you are strongly advised to rerun the model , entering slightly different values for variables where you have provided a “best guess”, such as entering high and low estimates for such variables.

HEAT estimate

04 December 2015 - 21:19 (v2.3)

Reduced mortality as a result of changes in cycling behaviour

The cycling data you have entered corresponds to an average of 83.33 hours per person per year.

This level of cycling provides an estimated protective benefit of: 10 % (compared to persons not cycling regularly)

From the data you have entered, the number of individuals who benefit from this level of cycling is: 317

Out of this many individuals, the number who would be expected to die if they were not cycling regularly would be: 0.50

The number of deaths per year that are prevented by this level of cycling is: less than 1

Economic value of cycling

Currency: EUR, rounded to 1000

The value of statistical life applied is: 1,000,000 EUR	
The annual benefit of this level of cycling, per year, is:	48,000 EUR
The total benefits accumulated over 15 years are:	727,000 EUR
When future benefits are discounted by 3 % per year:	
the current value of the average annual benefit, averaged across 15 years is:	39,000 EUR
the current value of the total benefits accumulated over 15 years is:	579,000 EUR

Please bear in mind that HEAT does not calculate risk reductions for individual persons but an average across the population under study. The results should not be misunderstood to represent individual risk reductions. Also note that the VSL not assign a value to the life of one particular person but refers to an average value of a “statistical life”.

It is important to remember that many of the variables used within this HEAT calculation are estimates and therefore liable to some degree of error.

You are reminded that the HEAT tools provide you with an approximation of the level of health benefits. To get a better sense for the possible range of the results, you are strongly advised to rerun the model , entering slightly different values for variables where you have provided a “best guess”, such as entering high and low estimates for such variables.

HEAT estimate

04 December 2015 - 21:05 (v2.3)

Reduced mortality as a result of changes in cycling behaviour

The cycling data you have entered corresponds to an average of 83.33 hours per person per year.

This level of cycling provides an estimated protective benefit of: 10 % (compared to persons not cycling regularly)

From the data you have entered, the number of individuals who benefit from this level of cycling is: 568

Out of this many individuals, the number who would be expected to die if they were not cycling regularly would be: 0.90

The number of deaths per year that are prevented by this level of cycling is: less than 1

Economic value of cycling

Currency: EUR, rounded to 1000

The value of statistical life applied is: 1,000,000 EUR	
The annual benefit of this level of cycling, per year, is:	87,000 EUR
The total benefits accumulated over 15 years are:	1,303,000 EUR
When future benefits are discounted by 3 % per year:	
the current value of the average annual benefit, averaged across 15 years is:	69,000 EUR
the current value of the total benefits accumulated over 15 years is:	1,037,000 EUR

Please bear in mind that HEAT does not calculate risk reductions for individual persons but an average across the population under study. The results should not be misunderstood to represent individual risk reductions. Also note that the VSL not assign a value to the life of one particular person but refers to an average value of a “statistical life”.

It is important to remember that many of the variables used within this HEAT calculation are estimates and therefore liable to some degree of error.

You are reminded that the HEAT tools provide you with an approximation of the level of health benefits. To get a better sense for the possible range of the results, you are strongly advised to rerun the model , entering slightly different values for variables where you have provided a “best guess”, such as entering high and low estimates for such variables.

HEAT estimate

04 December 2015 - 21:07 (v2.3)

Reduced mortality as a result of changes in cycling behaviour

The cycling data you have entered corresponds to an average of 83.33 hours per person per year.

This level of cycling provides an estimated protective benefit of: 10 % (compared to persons not cycling regularly)

From the data you have entered, the number of individuals who benefit from this level of cycling is: 427

Out of this many individuals, the number who would be expected to die if they were not cycling regularly would be: 0.68

The number of deaths per year that are prevented by this level of cycling is: less than 1

Economic value of cycling

Currency: EUR, rounded to 1000

The value of statistical life applied is: 1,000,000 EUR	
The annual benefit of this level of cycling, per year, is:	65,000 EUR
The total benefits accumulated over 15 years are:	979,000 EUR
When future benefits are discounted by 3 % per year:	
the current value of the average annual benefit, averaged across 15 years is:	52,000 EUR
the current value of the total benefits accumulated over 15 years is:	780,000 EUR

Please bear in mind that HEAT does not calculate risk reductions for individual persons but an average across the population under study. The results should not be misunderstood to represent individual risk reductions. Also note that the VSL not assign a value to the life of one particular person but refers to an average value of a “statistical life”.

It is important to remember that many of the variables used within this HEAT calculation are estimates and therefore liable to some degree of error.

You are reminded that the HEAT tools provide you with an approximation of the level of health benefits. To get a better sense for the possible range of the results, you are strongly advised to rerun the model , entering slightly different values for variables where you have provided a “best guess”, such as entering high and low estimates for such variables.

HEAT estimate

04 December 2015 - 21:10 (v2.3)

Reduced mortality as a result of changes in cycling behaviour

The cycling data you have entered corresponds to an average of 83.33 hours per person per year.

This level of cycling provides an estimated protective benefit of: 10 % (compared to persons not cycling regularly)

From the data you have entered, the number of individuals who benefit from this level of cycling is: 320

Out of this many individuals, the number who would be expected to die if they were not cycling regularly would be: 0.51

The number of deaths per year that are prevented by this level of cycling is: less than 1

Economic value of cycling

Currency: EUR, rounded to 1000

The value of statistical life applied is: 1,000,000 EUR	
The annual benefit of this level of cycling, per year, is:	49,000 EUR
The total benefits accumulated over 15 years are:	734,000 EUR
When future benefits are discounted by 3 % per year:	
the current value of the average annual benefit, averaged across 15 years is:	39,000 EUR
the current value of the total benefits accumulated over 15 years is:	584,000 EUR

Please bear in mind that HEAT does not calculate risk reductions for individual persons but an average across the population under study. The results should not be misunderstood to represent individual risk reductions. Also note that the VSL not assign a value to the life of one particular person but refers to an average value of a “statistical life”.

It is important to remember that many of the variables used within this HEAT calculation are estimates and therefore liable to some degree of error.

You are reminded that the HEAT tools provide you with an approximation of the level of health benefits. To get a better sense for the possible range of the results, you are strongly advised to rerun the model , entering slightly different values for variables where you have provided a “best guess”, such as entering high and low estimates for such variables.

HEAT estimate

04 December 2015 - 21:09 (v2.3)

Reduced mortality as a result of changes in cycling behaviour

The cycling data you have entered corresponds to an average of 83.33 hours per person per year.

This level of cycling provides an estimated protective benefit of: 10 % (compared to persons not cycling regularly)

From the data you have entered, the number of individuals who benefit from this level of cycling is: 284

Out of this many individuals, the number who would be expected to die if they were not cycling regularly would be: 0.45

The number of deaths per year that are prevented by this level of cycling is: less than 1

Economic value of cycling

Currency: EUR, rounded to 1000

The value of statistical life applied is: 1,000,000 EUR	
The annual benefit of this level of cycling, per year, is:	43,000 EUR
The total benefits accumulated over 15 years are:	651,000 EUR
When future benefits are discounted by 3 % per year:	
the current value of the average annual benefit, averaged across 15 years is:	35,000 EUR
the current value of the total benefits accumulated over 15 years is:	518,000 EUR

Please bear in mind that HEAT does not calculate risk reductions for individual persons but an average across the population under study. The results should not be misunderstood to represent individual risk reductions. Also note that the VSL not assign a value to the life of one particular person but refers to an average value of a “statistical life”.

It is important to remember that many of the variables used within this HEAT calculation are estimates and therefore liable to some degree of error.

You are reminded that the HEAT tools provide you with an approximation of the level of health benefits. To get a better sense for the possible range of the results, you are strongly advised to rerun the model , entering slightly different values for variables where you have provided a “best guess”, such as entering high and low estimates for such variables.

HEAT estimate

04 December 2015 - 21:11 (v2.3)

Reduced mortality as a result of changes in cycling behaviour

The cycling data you have entered corresponds to an average of 83.33 hours per person per year.

This level of cycling provides an estimated protective benefit of: 10 % (compared to persons not cycling regularly)

From the data you have entered, the number of individuals who benefit from this level of cycling is: 213

Out of this many individuals, the number who would be expected to die if they were not cycling regularly would be: 0.34

The number of deaths per year that are prevented by this level of cycling is: less than 1

Economic value of cycling

Currency: EUR, rounded to 1000

The value of statistical life applied is: 1,000,000 EUR	
The annual benefit of this level of cycling, per year, is:	33,000 EUR
The total benefits accumulated over 15 years are:	489,000 EUR
When future benefits are discounted by 3 % per year:	
the current value of the average annual benefit, averaged across 15 years is:	26,000 EUR
the current value of the total benefits accumulated over 15 years is:	389,000 EUR

Please bear in mind that HEAT does not calculate risk reductions for individual persons but an average across the population under study. The results should not be misunderstood to represent individual risk reductions. Also note that the VSL not assign a value to the life of one particular person but refers to an average value of a “statistical life”.

It is important to remember that many of the variables used within this HEAT calculation are estimates and therefore liable to some degree of error.

You are reminded that the HEAT tools provide you with an approximation of the level of health benefits. To get a better sense for the possible range of the results, you are strongly advised to rerun the model , entering slightly different values for variables where you have provided a “best guess”, such as entering high and low estimates for such variables.

HEAT estimate

04 December 2015 - 21:11 (v2.3)

Reduced mortality as a result of changes in cycling behaviour

The cycling data you have entered corresponds to an average of 83.33 hours per person per year.

This level of cycling provides an estimated protective benefit of: 10 % (compared to persons not cycling regularly)

From the data you have entered, the number of individuals who benefit from this level of cycling is: 847

Out of this many individuals, the number who would be expected to die if they were not cycling regularly would be: 1.35

The number of deaths per year that are prevented by this level of cycling is: less than 1

Economic value of cycling

Currency: EUR, rounded to 1000

The value of statistical life applied is: 1,000,000 EUR	
The annual benefit of this level of cycling, per year, is:	130,000 EUR
The total benefits accumulated over 15 years are:	1,943,000 EUR
When future benefits are discounted by 3 % per year:	
the current value of the average annual benefit, averaged across 15 years is:	103,000 EUR
the current value of the total benefits accumulated over 15 years is:	1,546,000 EUR

Please bear in mind that HEAT does not calculate risk reductions for individual persons but an average across the population under study. The results should not be misunderstood to represent individual risk reductions. Also note that the VSL not assign a value to the life of one particular person but refers to an average value of a “statistical life”.

It is important to remember that many of the variables used within this HEAT calculation are estimates and therefore liable to some degree of error.

You are reminded that the HEAT tools provide you with an approximation of the level of health benefits. To get a better sense for the possible range of the results, you are strongly advised to rerun the model , entering slightly different values for variables where you have provided a “best guess”, such as entering high and low estimates for such variables.

J.3 PEAK SPREADING AND THE OVERSPILL OF VEHICLES

Table J.16:20-year traffic growth on the R44 corridor, the resulting spillover to an earlier time period once capacity is reached and the resultant vehicle-trip savings in the AM-peak hour..

	SCENARIO	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
volumes with 3% growth		2,113	2,176	2,242	2,309	2,378	2,450	2,523	2,599	2,677	2,757	2,840	2,925	3,013	3,103	3,196	3,292	3,391	3,492	3,597	3,705	3,816
overspill										77	157	240	325	413	503	596	692	791	892	997	1,105	1,216
potential users (vehicles)	B2B5	266					308	318	327	337	347	357	368	379	391	402	414	427	440	453	466	480
cars left on the road							2,141	2,205	2,272	2,340	2,410	2,482	2,557	2,633	2,712	2,794	2,878	2,964	3,053	3,144	3,239	3,336
potential users subtracted in the AM peak hour							308	318	327	260	190	118	43	-33	-112	-194	-278	-364	-453	-544	-639	-736
potential users (vehicles)	B2M7&M1B5	200					232	239	246	253	261	269	277	285	294	303	312	321	331	340	351	361
cars left on the road							2,218	2,284	2,353	2,423	2,496	2,571	2,648	2,727	2,809	2,894	2,980	3,070	3,162	3,257	3,354	3,455
potential users subtracted in the AM peak hour							232	239	246	177	104	29	-48	-127	-209	-294	-380	-470	-562	-657	-754	-855
potential users (vehicles)	M1M7	150					174	179	184	190	196	202	208	214	220	227	234	241	248	255	263	271
cars left on the road							2,276	2,344	2,414	2,487	2,561	2,638	2,717	2,799	2,883	2,969	3,058	3,150	3,245	3,342	3,442	3,545
potential users subtracted in the AM peak hour							174	179	184	113	39	-38	-117	-199	-283	-369	-458	-550	-645	-742	-842	-945
potential users (vehicles)	B2M10&M4B5	133					154	159	164	168	174	179	184	190	195	201	207	213	220	226	233	240
cars left on the road							2,295	2,364	2,435	2,508	2,583	2,661	2,741	2,823	2,908	2,995	3,085	3,177	3,273	3,371	3,472	3,576
potential users subtracted in the AM peak hour							154	159	164	92	17	-61	-141	-223	-308	-395	-485	-577	-673	-771	-872	-976
potential users (vehicles)	M1M10&M4M7	100					116	119	123	127	130	134	138	143	147	151	156	160	165	170	175	181
cars left on the road							2,334	2,404	2,476	2,550	2,627	2,705	2,786	2,870	2,956	3,045	3,136	3,230	3,327	3,427	3,530	3,636
potential users subtracted in the AM peak hour							116	119	123	50	-27	-105	-186	-270	-356	-445	-536	-630	-727	-827	-930	-1,036
potential users (vehicles)	B2B3B5B6	691					801	825	850	875	902	929	957	985	1,015	1,045	1,077	1,109	1,142	1,176	1,212	1,248
cars left on the road							1,648	1,698	1,749	1,801	1,855	1,911	1,968	2,027	2,088	2,151	2,215	2,282	2,350	2,421	2,493	2,568
potential users subtracted in the AM peak hour							801	825	850	799	745	689	632	573	512	449	385	318	250	179	107	32
potential users (vehicles)	B2B3M7M8&M1M2B5B6	519					602	620	638	657	677	697	718	740	762	785	809	833	858	884	910	937
cars left on the road							1,848	1,903	1,960	2,019	2,080	2,142	2,206	2,273	2,341	2,411	2,483	2,558	2,635	2,714	2,795	2,879
potential users subtracted in the AM peak hour							602	620	638	581	520	458	394	327	259	189	117	42	-35	-114	-195	-279
potential users (vehicles)	M1M2M7M8	389					451	464	478	493	508	523	538	555	571	588	606	624	643	662	682	703

cars left on the road							1,999	2,059	2,120	2,184	2,249	2,317	2,386	2,458	2,532	2,608	2,686	2,767	2,850	2,935	3,023	3,114
potential users subtracted in the AM peak hour							451	464	478	416	351	283	214	142	68	-8	-86	-167	-250	-335	-423	-514
potential users (vehicles)	B2B3M10M11&M4M5B5B6	346					401	413	426	438	451	465	479	493	508	523	539	555	572	589	607	625
cars left on the road							2,048	2,110	2,173	2,238	2,306	2,375	2,446	2,519	2,595	2,673	2,753	2,836	2,921	3,008	3,098	3,191
potential users subtracted in the AM peak hour							401	413	426	362	294	225	154	81	5	-73	-153	-236	-321	-408	-498	-591
potential users (vehicles)	M1M2M10M11&M4M5M7M8	259					300	309	319	328	338	348	359	369	380	392	404	416	428	441	454	468
cars left on the road							2,149	2,214	2,280	2,349	2,419	2,492	2,566	2,643	2,723	2,804	2,888	2,975	3,064	3,156	3,251	3,349
potential users subtracted in the AM peak hour							300	309	319	251	181	108	34	-43	-123	-204	-288	-375	-464	-556	-651	-749
potential users (vehicles)	B2B3B4B5B6B7	916					1,062	1,094	1,127	1,160	1,195	1,231	1,268	1,306	1,345	1,386	1,427	1,470	1,514	1,559	1,606	1,654
cars left on the road							1,388	1,429	1,472	1,516	1,562	1,609	1,657	1,707	1,758	1,811	1,865	1,921	1,978	2,038	2,099	2,162
potential users subtracted in the AM peak hour							1,062	1,094	1,127	1,084	1,038	991	943	893	842	789	735	679	622	562	501	438
potential users (vehicles)	B2B3B4M7M8M9&M1M2M3B5B6B7	688					798	822	846	872	898	925	952	981	1,010	1,041	1,072	1,104	1,137	1,171	1,206	1,243
cars left on the road							1,652	1,702	1,753	1,805	1,859	1,915	1,973	2,032	2,093	2,155	2,220	2,287	2,355	2,426	2,499	2,574
potential users subtracted in the AM peak hour							798	822	846	795	741	685	627	568	507	445	380	313	245	174	101	26
potential users (vehicles)	M1M2M3M7M8M9	516					598	616	635	654	673	693	714	736	758	780	804	828	853	878	905	932
cars left on the road							1,851	1,907	1,964	2,023	2,084	2,146	2,211	2,277	2,345	2,416	2,488	2,563	2,640	2,719	2,800	2,884
potential users subtracted in the AM peak hour							598	616	635	577	516	454	389	323	255	184	112	37	-40	-119	-200	-284
potential users (vehicles)	B2B3B4M10M11M12M13&M4M5M6B5B6B7	459					532	548	565	581	599	617	635	654	674	694	715	737	759	781	805	829
cars left on the road							1,917	1,975	2,034	2,095	2,158	2,223	2,290	2,358	2,429	2,502	2,577	2,654	2,734	2,816	2,900	2,987
potential users subtracted in the AM peak hour							532	548	565	505	442	377	310	242	171	98	23	-54	-134	-216	-300	-387
potential users (vehicles)	M1M2M3M10M11M12&M4M5M6M7M8M9	343					398	410	422	435	448	461	475	489	504	519	534	550	567	584	601	619
cars left on the road							2,052	2,113	2,177	2,242	2,309	2,379	2,450	2,524	2,599	2,677	2,758	2,840	2,926	3,013	3,104	3,197
potential users subtracted in the AM peak hour							398	410	422	358	291	221	150	76	1	-77	-158	-240	-326	-413	-504	-597

K. CHAPTER 14 APPENDIX: GEOMETRIC IMPROVEMENT ALTERNATIVE

Table K.1: 2020 Control delay, level of service and back of queue per turning movement at main node 4 (intersection 2 in terms of the numbering system used for the traffic volume study) for the geometric-improvement alternative.

R44 / Van Reede Signalised Intersection_2020 Geometric Improvement										
Approach	N			E		S			W	
Lane Group	L	C	R	L	C	L	C	R	C	R
di, Lane Group Delay (s/veh)	44.10	265.29	80.88	22.59	70.79	37.32	339.58	73.83	59.16	71.32
LOS	D	F	F	C	E	D	F	E	E	E
dA, Approach Delay (s/veh)	234.68			30.67		232.87			63.74	
Approach LOS	F			C		F			E	
dI, Intersection Delay (s/veh)	179.96									
Intersection LOS	F									
Q, Average Back of Queue (veh)	5.14	83.72	2.11	24.07	9.04	8.01	101.09	1.28	8.73	6.39
Q_{90} Percentile Back of Queue (veh)	8.63	123.58	3.86	36.20	14.30	12.82	151.64	2.41	13.85	10.47

Table K.2: 2020 Control delay, level of service and back of queue per turning movement at main node 4 (intersection 2 in terms of the numbering system used for the traffic volume study) for the null alternative.

R44 / Van Reede Signalised Intersection_2020 null alternative										
Approach	N			E		S			W	
Lane Group	L	C	R	L	C	L	C	R	C	R
di, Lane Group Delay (s/veh)	44.10	265.29	80.88	125.53	70.79	37.32	339.58	319.79	59.16	71.32
LOS	D	F	F	C	E	D	F	E	E	E
dA, Approach Delay (s/veh)	234.68			116.35		304.04			63.74	
Approach LOS	F			F		F			E	
dI, Intersection Delay (s/veh)	179.96									
Intersection LOS	F									
Q, Average Back of Queue (veh)	5.14	83.72	2.11	64.03	9.04	8.01	101.09	46.86	8.73	6.39
Q_{90} Percentile Back of Queue (veh)	8.63	123.58	3.86	96.05	14.30	12.82	151.64	70.29	13.85	10.47

L. CHAPTER 15 APPENDIX: COST / BENEFIT ANALYSIS

L.1 FYRR RESULTS PER ALTERNATIVE AND SCENARIO

Table L.1: FYRR for the bicycle-sharing and geometric improvement alternatives.

SCENARIO	FYRR			
	with VOT 1	with VOT 2	with VOT 3	with VOT 4
S2	0.79	0.57	0.70	0.52
S3	0.47	0.35	0.42	0.32
S4	0.45	0.33	0.40	0.31
S5	0.89	0.64	0.79	0.59
S6	0.54	0.39	0.48	0.36
S7	0.51	0.38	0.45	0.35
S8	0.80	0.57	0.71	0.53
S9	0.48	0.35	0.43	0.33
S10	0.46	0.34	0.41	0.32
S11	0.89	0.64	0.79	0.59
S12	0.54	0.40	0.48	0.37
S13	0.52	0.38	0.46	0.36
S14	0.79	0.56	0.70	0.52
S15	0.47	0.34	0.42	0.32
S16	0.44	0.33	0.40	0.30
S17	0.88	0.63	0.78	0.58
S18	0.53	0.39	0.47	0.36
S19	0.50	0.37	0.45	0.34
S20	0.60	0.42	0.53	0.39
S21	0.37	0.27	0.33	0.25
S22	0.33	0.25	0.30	0.23
S23	0.67	0.48	0.59	0.44
S24	0.42	0.30	0.37	0.28
S25	0.38	0.28	0.34	0.26
S26	0.60	0.43	0.53	0.39
S27	0.37	0.27	0.33	0.25
S28	0.34	0.25	0.30	0.23
S29	0.67	0.48	0.59	0.44
S30	0.42	0.31	0.38	0.29
S31	0.38	0.28	0.34	0.26
S32	0.59	0.42	0.52	0.39
S33	0.37	0.27	0.33	0.25
S34	0.33	0.24	0.29	0.22
S35	0.66	0.47	0.59	0.43
S36	0.41	0.30	0.37	0.28
S37	0.37	0.27	0.33	0.25
S38	0.43	0.30	0.38	0.28
S39	0.27	0.20	0.24	0.18
S40	0.24	0.18	0.22	0.17
S41	0.48	0.34	0.42	0.31
S42	0.31	0.22	0.28	0.21
S43	0.28	0.20	0.25	0.19
S44	0.43	0.30	0.38	0.28
S45	0.28	0.20	0.25	0.19
S46	0.25	0.18	0.22	0.17
S47	0.48	0.34	0.43	0.31
S48	0.31	0.23	0.28	0.21
S49	0.28	0.21	0.25	0.19
S50	0.43	0.30	0.38	0.28
S51	0.27	0.20	0.24	0.18
S52	0.24	0.18	0.21	0.16
S53	0.48	0.34	0.42	0.31
S54	0.31	0.22	0.27	0.20
S55	0.27	0.20	0.24	0.18
S56	0.71	0.51	0.63	0.47
S57	0.44	0.32	0.40	0.30
S58	0.40	0.30	0.36	0.28
S59	0.80	0.57	0.70	0.52
S60	0.50	0.36	0.44	0.34
S61	0.45	0.33	0.40	0.31
S62	0.72	0.51	0.63	0.47
S63	0.45	0.33	0.40	0.30
S64	0.41	0.30	0.36	0.28
S65	0.80	0.57	0.71	0.53
S66	0.50	0.37	0.45	0.34
S67	0.46	0.34	0.41	0.32
S68	0.71	0.50	0.63	0.46
S69	0.44	0.32	0.39	0.29
S70	0.40	0.29	0.35	0.27
S71	0.79	0.56	0.70	0.52
S72	0.49	0.36	0.44	0.33
S73	0.45	0.33	0.40	0.31
S74	0.56	0.40	0.49	0.36

S75	0.36	0.26	0.32	0.24
S76	0.32	0.24	0.29	0.22
S77	0.62	0.44	0.55	0.41
S78	0.40	0.29	0.36	0.27
S79	0.36	0.27	0.32	0.25
S80	0.56	0.40	0.50	0.37
S81	0.36	0.26	0.32	0.24
S82	0.32	0.24	0.29	0.22
S83	0.63	0.45	0.55	0.41
S84	0.41	0.29	0.36	0.27
S85	0.37	0.27	0.33	0.25
S86	0.55	0.39	0.49	0.36
S87	0.35	0.26	0.31	0.24
S88	0.32	0.23	0.28	0.21
S89	0.62	0.44	0.55	0.40
S90	0.40	0.29	0.35	0.26
S91	0.36	0.26	0.32	0.24
S92	0.41	0.29	0.36	0.27
S93	0.27	0.19	0.24	0.18
S94	0.24	0.18	0.22	0.16
S95	0.46	0.32	0.41	0.30
S96	0.30	0.22	0.27	0.20
S97	0.27	0.20	0.24	0.18
S98	0.41	0.29	0.37	0.27
S99	0.27	0.19	0.24	0.18
S100	0.25	0.18	0.22	0.17
S101	0.46	0.33	0.41	0.30
S102	0.30	0.22	0.27	0.20
S103	0.28	0.20	0.25	0.19
S104	0.41	0.29	0.36	0.26
S105	0.27	0.19	0.24	0.17
S106	0.24	0.17	0.21	0.16
S107	0.46	0.32	0.40	0.29
S108	0.30	0.21	0.27	0.20
S109	0.27	0.20	0.24	0.18
S110	0.64	0.45	0.56	0.41
S111	0.41	0.30	0.36	0.27
S112	0.39	0.29	0.35	0.27
S113	0.71	0.50	0.63	0.46
S114	0.46	0.33	0.41	0.31
S115	0.44	0.32	0.39	0.30
S116	0.64	0.45	0.57	0.42
S117	0.42	0.30	0.37	0.28
S118	0.40	0.29	0.35	0.27
S119	0.71	0.51	0.63	0.46
S120	0.46	0.34	0.41	0.31
S121	0.45	0.33	0.40	0.30
S122	0.63	0.45	0.56	0.41
S123	0.41	0.29	0.36	0.27
S124	0.39	0.28	0.35	0.26
S125	0.71	0.50	0.62	0.46
S126	0.45	0.33	0.40	0.30
S127	0.44	0.32	0.39	0.29
S128	0.51	0.36	0.45	0.33
S129	0.34	0.24	0.30	0.22
S130	0.32	0.23	0.29	0.22
S131	0.57	0.40	0.50	0.37
S132	0.37	0.27	0.33	0.25
S133	0.36	0.26	0.32	0.24
S134	0.52	0.36	0.46	0.33
S135	0.34	0.24	0.30	0.22
S136	0.33	0.24	0.29	0.22
S137	0.58	0.41	0.51	0.37
S138	0.38	0.27	0.34	0.25
S139	0.37	0.27	0.33	0.25
S140	0.51	0.36	0.45	0.33
S141	0.33	0.24	0.29	0.22
S142	0.32	0.23	0.28	0.21
S143	0.57	0.40	0.50	0.37
S144	0.37	0.27	0.33	0.24
S145	0.36	0.26	0.32	0.24
S146 = geometric improvement alternative	0.65	0.44	0.57	0.39
MIN	0.24	0.17	0.21	0.16
MAX	0.89	0.64	0.79	0.59
MEAN	0.37			

L.2 NPV RESULTS PER ALTERNATIVE AND SCENARIO

Table L.2: NVP (with travel-cost benefits for year 1 only) for the bicycle-sharing and geometric improvement alternatives.

SCENARIO	NPV			
	with VOT 1	with VOT 2	with VOT 3	with VOT 4
S2	13,697,531	7,340,646	11,154,777	6,069,269
S3	13,596,659	5,120,530	10,206,206	3,425,303
S4	19,193,217	9,691,932	15,263,565	7,727,106
S5	16,734,462	10,377,578	14,191,709	9,106,200
S6	21,176,441	12,700,312	17,785,988	11,005,085
S7	28,761,449	19,260,164	24,831,797	17,295,338
S8	16,030,619	9,673,735	13,487,866	8,402,357
S9	19,268,297	10,792,167	15,877,844	9,096,941
S10	26,670,947	17,169,662	22,741,295	15,204,836
S11	19,067,551	12,710,667	16,524,798	11,439,289
S12	26,848,079	18,371,949	23,457,626	16,676,723
S13	36,239,179	26,737,894	32,309,527	24,773,068
S14	11,788,640	5,431,755	9,245,886	4,160,378
S15	8,956,229	480,099	5,565,776	-1,215,127
S16	13,075,074	3,573,789	9,145,422	1,608,963
S17	14,825,571	8,468,687	12,282,818	7,197,309
S18	16,536,011	8,059,881	13,145,558	6,364,655
S19	22,643,306	13,142,021	18,713,654	11,177,195
S20	1,119,983	-3,732,465	-820,996	-4,702,954
S21	-5,397,561	-12,084,706	-8,072,418	-13,422,135
S22	-6,335,635	-13,361,323	-9,243,111	-14,815,062
S23	4,156,915	-695,533	2,215,936	-1,666,022
S24	2,182,221	-4,504,924	-492,636	-5,842,353
S25	3,232,597	-3,793,091	325,121	-5,246,830
S26	2,617,837	-2,234,611	676,858	-3,205,100
S27	-1,128,878	-7,816,023	-3,803,735	-9,153,452
S28	-708,455	-7,734,143	-3,615,931	-9,187,882
S29	5,654,769	802,321	3,713,790	-168,168
S30	6,450,904	-236,241	3,776,047	-1,573,670
S31	8,859,777	1,834,089	5,952,301	380,350
S32	-105,535	-4,957,982	-2,046,514	-5,928,472
S33	-8,890,120	-15,577,265	-11,564,977	-16,914,694
S34	-10,939,692	-17,965,380	-13,847,167	-19,419,118
S35	2,931,397	-1,921,050	990,418	-2,891,540
S36	-1,310,338	-7,997,483	-3,985,195	-9,334,912
S37	-1,371,460	-8,397,148	-4,278,935	-9,850,886
S38	-7,822,985	-11,372,942	-9,242,968	-12,082,933
S39	-23,909,419	-29,007,133	-25,948,504	-30,026,676
S40	-29,547,868	-34,882,183	-31,746,394	-35,981,446
S41	-4,786,054	-8,336,011	-6,206,036	-9,046,001
S42	-16,329,637	-21,427,351	-18,368,722	-22,446,893
S43	-19,979,636	-25,313,951	-22,178,162	-26,413,214
S44	-6,823,512	-10,373,469	-8,243,494	-11,083,459
S45	-21,056,688	-26,154,402	-23,095,773	-27,173,944
S46	-25,792,485	-31,126,800	-27,991,011	-32,226,063
S47	-3,786,580	-7,336,537	-5,206,562	-8,046,527
S48	-13,476,906	-18,574,620	-15,515,991	-19,594,162
S49	-16,224,253	-21,558,568	-18,422,779	-22,657,831
S50	-8,640,737	-12,190,694	-10,060,719	-12,900,684
S51	-26,243,472	-31,341,186	-28,282,557	-32,360,728
S52	-32,620,454	-37,954,769	-34,818,980	-39,054,032
S53	-5,603,805	-9,153,762	-7,023,787	-9,863,752
S54	-18,663,690	-23,761,404	-20,702,775	-24,780,946
S55	-23,052,222	-28,386,537	-25,250,748	-29,485,800
S56	5,756,511	904,064	3,815,532	-66,426
S57	5,586,060	-1,101,085	2,911,203	-2,438,514
S58	7,754,010	728,322	4,846,535	-725,416
S59	8,247,372	3,394,924	6,306,393	2,424,435
S60	11,707,044	5,019,898	9,032,470	3,682,470
S61	15,416,789	8,391,101	12,509,314	6,937,363
S62	7,254,366	2,401,918	5,313,387	1,431,429
S63	9,854,744	3,167,598	7,179,887	1,830,170
S64	13,381,190	6,355,502	10,473,715	4,901,764
S65	9,745,226	4,892,779	7,804,247	3,922,289
S66	15,975,727	9,288,581	13,300,870	7,951,153
S67	21,043,969	14,018,281	18,136,494	12,564,543
S68	4,530,994	-321,453	2,590,015	-1,291,943
S69	2,093,502	-4,593,644	-581,355	-5,931,072
S70	3,149,954	-3,875,734	242,478	-5,329,473
S71	7,021,855	2,169,407	5,080,876	1,198,918
S72	8,214,485	1,527,339	5,539,628	189,911
S73	10,812,733	3,787,045	7,905,257	2,333,306
S74	-1,070,828	-4,913,840	-2,608,032	-5,682,443
S75	-8,326,096	-13,814,435	-10,521,431	-14,912,104

S76	-9,665,139	-15,397,259	-12,031,119	-16,580,249
S77	1,420,033	-2,422,979	-117,172	-3,191,582
S78	-2,205,113	-7,693,452	-4,400,448	-8,791,121
S79	-2,002,360	-7,734,479	-4,368,340	-8,917,469
S80	50,472	-3,792,540	-1,486,732	-4,561,143
S81	-5,120,280	-10,608,620	-7,315,616	-11,706,288
S82	-5,436,523	-11,168,643	-7,802,503	-12,351,633
S83	2,541,333	-1,301,679	1,004,128	-2,070,282
S84	1,000,703	-4,487,637	-1,194,633	-5,585,305
S85	2,226,256	-3,505,864	-139,724	-4,688,854
S86	-1,988,255	-5,831,267	-3,525,460	-6,599,870
S87	-10,949,035	-16,437,375	-13,144,371	-17,535,043
S88	-13,124,916	-18,857,035	-15,490,896	-20,040,025
S89	502,605	-3,340,407	-1,034,599	-4,109,010
S90	-4,828,052	-10,316,392	-7,023,388	-11,414,060
S91	-5,462,136	-11,194,256	-7,828,116	-12,377,246
S92	-7,618,298	-10,524,373	-8,780,728	-11,105,587
S93	-22,303,943	-26,549,940	-24,002,342	-27,399,140
S94	-27,047,477	-31,540,856	-28,892,966	-32,463,600
S95	-5,127,437	-8,033,512	-6,289,867	-8,614,726
S96	-16,182,960	-20,428,957	-17,881,359	-21,278,157
S97	-19,384,698	-23,878,077	-21,230,187	-24,800,821
S98	-6,868,015	-9,774,089	-8,030,444	-10,355,303
S99	-20,155,457	-24,401,455	-21,853,856	-25,250,654
S100	-24,227,598	-28,720,977	-26,073,087	-29,643,721
S101	-4,377,154	-7,283,229	-5,539,584	-7,864,443
S102	-14,034,474	-18,280,472	-15,732,873	-19,129,671
S103	-16,564,819	-21,058,198	-18,410,308	-21,980,942
S104	-8,232,166	-11,138,241	-9,394,596	-11,719,455
S105	-24,061,794	-28,307,792	-25,760,193	-29,156,991
S106	-29,354,650	-33,848,029	-31,200,139	-34,770,774
S107	-5,741,306	-8,647,380	-6,903,735	-9,228,594
S108	-17,940,811	-22,186,809	-19,639,210	-23,036,008
S109	-21,691,871	-26,185,250	-23,537,360	-27,107,995
S110	1,495,087	-2,054,870	75,104	-2,764,861
S111	-1,807,132	-6,904,846	-3,846,217	-7,924,388
S112	1,376,496	-3,957,819	-822,030	-5,057,082
S113	3,434,574	-115,383	2,014,592	-825,373
S114	2,836,804	-2,260,910	797,719	-3,280,452
S115	6,926,687	1,592,372	4,728,161	493,109
S116	2,494,560	-1,055,397	1,074,578	-1,765,387
S117	1,045,600	-4,052,114	-993,485	-5,071,657
S118	5,131,879	-202,436	2,933,353	-1,301,699
S119	4,434,048	884,091	3,014,066	174,101
S120	5,689,536	591,822	3,650,451	-427,721
S121	10,682,069	5,347,754	8,483,543	4,248,491
S122	677,336	-2,872,621	-742,647	-3,582,612
S123	-4,141,184	-9,238,898	-6,180,269	-10,258,441
S124	-1,696,089	-7,030,404	-3,894,615	-8,129,667
S125	2,616,823	-933,134	1,196,841	-1,643,124
S126	502,752	-4,594,962	-1,536,333	-5,614,505
S127	3,854,101	-1,480,214	1,655,575	-2,579,477
S128	-2,936,754	-5,842,829	-4,099,184	-6,424,043
S129	-11,185,277	-15,431,274	-12,883,676	-16,280,474
S130	-10,212,758	-14,706,137	-12,058,247	-15,628,881
S131	-997,267	-3,903,341	-2,159,696	-4,484,555
S132	-6,541,341	-10,787,338	-8,239,740	-11,636,538
S133	-4,662,567	-9,155,946	-6,508,056	-10,078,691
S134	-2,186,471	-5,092,546	-3,348,901	-5,673,760
S135	-9,036,792	-13,282,789	-10,735,191	-14,131,989
S136	-7,392,879	-11,886,258	-9,238,368	-12,809,003
S137	-246,983	-3,153,058	-1,409,413	-3,734,272
S138	-4,392,856	-8,638,853	-6,091,255	-9,488,053
S139	-1,842,689	-6,336,068	-3,688,178	-7,258,812
S140	-3,550,623	-6,456,697	-4,713,052	-7,037,911
S141	-12,943,128	-17,189,126	-14,641,527	-18,038,325
S142	-12,519,932	-17,013,311	-14,365,421	-17,936,055
S143	-1,611,135	-4,517,210	-2,773,565	-5,098,424
S144	-8,299,192	-12,545,190	-9,997,591	-13,394,389
S145	-6,969,741	-11,463,120	-8,815,230	-12,385,865
S146 = geometric improvement alternative	-1,580,925	-2,581,198	-1,981,034	-2,781,252
MIN	-32,620,454	-37,954,769	-34,818,980	-39,054,032
MAX	36,239,179	26,737,894	32,309,527	24,773,068
MEAN	-4,882,751			

Table L.3: NVP (with travel-cost benefits for year 1 multiplied by factor of 7.5) for the bicycle-sharing and geometric improvement alternatives.

SCENARIO	NPV			
	with VOT 1	with VOT 2	with VOT 3	with VOT 4
S2	150,448,554	102,771,920	131,377,903	93,236,589
S3	196,614,865	133,043,894	171,186,467	120,329,695
S4	227,931,123	156,671,485	198,458,733	141,935,290
S5	153,485,486	105,808,852	134,414,835	96,273,521
S6	204,194,647	140,623,676	178,766,249	127,909,477
S7	237,499,355	166,239,717	208,026,965	151,503,522
S8	152,781,643	105,105,009	133,710,992	95,569,678
S9	202,286,502	138,715,531	176,858,105	126,001,332
S10	235,408,853	164,149,216	205,936,463	149,413,021
S11	155,818,575	108,141,941	136,747,924	98,606,610
S12	209,866,284	146,295,313	184,437,887	133,581,114
S13	244,977,085	173,717,448	215,504,695	158,981,253
S14	148,539,663	100,863,029	129,469,012	91,327,698
S15	191,974,434	128,403,463	166,546,037	115,689,264
S16	221,812,980	150,553,342	192,340,590	135,817,147
S17	151,576,595	103,899,961	132,505,944	94,364,630
S18	199,554,216	135,983,245	174,125,819	123,269,046
S19	231,381,212	160,121,574	201,908,822	145,385,379
S20	104,978,172	68,584,816	90,420,830	61,306,145
S21	137,901,543	87,747,952	117,840,116	77,717,238
S22	147,211,411	94,518,751	125,405,345	83,615,712
S23	108,015,104	71,621,748	93,457,762	64,343,077
S24	145,481,325	95,327,734	125,419,898	85,297,020
S25	156,779,643	104,086,983	134,973,577	93,183,944
S26	106,476,026	70,082,670	91,918,684	62,803,999
S27	142,170,226	92,016,635	122,108,799	81,985,921
S28	152,838,591	100,145,931	131,032,525	89,242,892
S29	109,512,958	73,119,602	94,955,616	65,840,931
S30	149,750,008	99,596,417	129,688,581	89,565,703
S31	162,406,823	109,714,163	140,600,757	98,811,124
S32	103,752,655	67,359,299	89,195,312	60,080,627
S33	134,408,984	84,255,393	114,347,557	74,224,679
S34	142,607,354	89,914,694	120,801,288	79,011,656
S35	106,789,587	70,396,231	92,232,244	63,117,559
S36	141,988,766	91,835,175	121,927,339	81,804,461
S37	152,175,586	99,482,926	130,369,520	88,579,888
S38	67,061,178	40,436,500	56,411,309	35,111,572
S39	83,598,790	45,365,935	68,305,653	37,719,366
S40	85,148,324	45,140,962	68,659,379	36,896,489
S41	70,098,110	43,473,432	59,448,241	38,148,503
S42	91,178,572	52,945,717	75,885,435	45,299,149
S43	94,716,556	54,709,194	78,227,611	46,464,721
S44	68,060,651	41,435,974	57,410,783	36,111,045
S45	86,451,521	48,218,666	71,158,384	40,572,098
S46	88,903,707	48,896,344	72,414,762	40,651,872
S47	71,097,583	44,472,906	60,447,715	39,147,977
S48	94,031,304	55,798,449	78,738,166	48,151,880
S49	98,471,939	58,464,576	81,982,994	50,220,104
S50	66,243,427	39,618,749	55,593,558	34,293,820
S51	81,264,737	43,031,882	65,971,600	35,385,314
S52	82,075,738	42,068,376	65,586,793	33,823,903
S53	69,280,358	42,655,681	58,630,490	37,330,752
S54	88,844,520	50,611,665	73,551,382	42,965,096
S55	91,643,970	51,636,608	75,155,025	43,392,135
S56	109,614,701	73,221,345	95,057,358	65,942,673
S57	148,885,164	98,731,573	128,823,737	88,700,859
S58	161,301,056	108,608,396	139,494,990	97,705,358
S59	112,105,561	75,712,205	97,548,219	68,433,534
S60	155,006,148	104,852,556	134,944,720	94,821,843
S61	168,963,836	116,271,176	147,157,769	105,368,137
S62	111,112,555	74,719,199	96,555,213	67,440,528
S63	153,153,848	103,000,256	133,092,420	92,969,543
S64	166,928,237	114,235,577	145,122,170	103,332,538
S65	113,603,416	77,210,059	99,046,073	69,931,388
S66	159,274,831	109,121,239	139,213,403	99,090,526
S67	174,591,016	121,898,356	152,784,949	110,995,317
S68	108,389,184	71,995,827	93,831,841	64,717,156
S69	145,392,606	95,239,014	125,331,178	85,208,301
S70	156,697,000	104,004,340	134,890,934	93,101,301
S71	110,880,044	74,486,688	96,322,702	67,208,017
S72	151,513,589	101,359,998	131,452,161	91,329,284
S73	164,359,779	111,667,119	142,553,713	100,764,080
S74	80,438,080	51,615,490	68,909,046	45,850,968
S75	107,995,753	66,833,207	91,530,737	58,600,693

S76	114,358,459	71,367,562	96,613,609	62,495,137
S77	82,928,941	54,106,351	71,399,907	48,341,828
S78	114,116,736	72,954,190	97,651,720	64,721,676
S79	122,021,238	79,030,342	104,276,388	70,157,917
S80	81,559,380	52,736,790	70,030,346	46,972,268
S81	111,201,568	70,039,022	94,736,552	61,806,508
S82	118,587,074	75,596,178	100,842,224	66,723,753
S83	84,050,241	55,227,651	72,521,207	49,463,128
S84	117,322,551	76,160,005	100,857,535	67,927,491
S85	126,249,853	83,258,957	108,505,003	74,386,532
S86	79,520,653	50,698,063	67,991,619	44,933,540
S87	105,372,813	64,210,267	88,907,797	55,977,753
S88	110,898,682	67,907,786	93,153,832	59,035,361
S89	82,011,513	53,188,923	70,482,480	47,424,401
S90	111,493,796	70,331,250	95,028,780	62,098,736
S91	118,561,461	75,570,565	100,816,611	66,698,140
S92	53,036,530	31,240,971	44,318,309	26,881,866
S93	66,283,212	34,438,231	53,545,219	28,069,234
S94	68,313,032	34,612,690	54,471,865	27,692,106
S95	55,527,391	33,731,832	46,809,169	29,372,727
S96	72,404,195	40,559,214	59,666,202	34,190,217
S97	75,975,811	42,275,469	62,134,644	35,354,885
S98	53,786,813	31,991,255	45,068,592	27,632,150
S99	68,431,697	36,586,716	55,693,705	30,217,720
S100	71,132,911	37,432,568	57,291,743	30,511,985
S101	56,277,674	34,482,115	47,559,453	30,123,010
S102	74,552,680	42,707,699	61,814,688	36,338,703
S103	78,795,690	45,095,348	64,954,523	38,174,764
S104	52,422,662	30,627,103	43,704,441	26,267,998
S105	64,525,360	32,680,379	51,787,368	26,311,383
S106	66,005,858	32,305,516	52,164,691	25,384,932
S107	54,913,522	33,117,964	46,195,301	28,758,859
S108	70,646,343	38,801,362	57,908,351	32,432,366
S109	73,668,638	39,968,295	59,827,470	33,047,711
S110	76,379,250	49,754,573	65,729,381	44,429,644
S111	105,701,078	67,468,223	90,407,940	59,821,654
S112	116,072,688	76,065,326	99,583,743	67,820,853
S113	78,318,738	51,694,060	67,668,869	46,369,131
S114	110,345,014	72,112,159	95,051,876	64,465,590
S115	121,622,879	81,615,516	105,133,934	73,371,044
S116	77,378,724	50,754,046	66,728,855	45,429,117
S117	108,553,809	70,320,954	93,260,671	62,674,385
S118	119,828,071	79,820,708	103,339,126	71,576,236
S119	79,318,211	52,693,534	68,668,343	47,368,605
S120	113,197,745	74,964,890	97,904,607	67,318,321
S121	125,378,261	85,370,899	108,889,316	77,126,426
S122	75,561,499	48,936,821	64,911,630	43,611,893
S123	103,367,025	65,134,170	88,073,887	57,487,601
S124	113,000,103	72,992,740	96,511,158	64,748,268
S125	77,500,987	50,876,309	66,851,118	45,551,380
S126	108,010,961	69,778,106	92,717,823	62,131,537
S127	118,550,293	78,542,931	102,061,348	70,298,458
S128	57,718,074	35,922,515	48,999,852	31,563,410
S129	77,401,878	45,556,896	64,663,885	39,187,900
S130	85,147,751	51,447,408	71,306,583	44,526,825
S131	59,657,561	37,862,002	50,939,340	33,502,897
S132	82,045,814	50,200,832	69,307,821	43,831,836
S133	90,697,941	56,997,599	76,856,774	50,077,015
S134	58,468,357	36,672,798	49,750,136	32,313,693
S135	79,550,363	47,705,382	66,812,370	41,336,385
S136	87,967,630	54,267,287	74,126,462	47,346,703
S137	60,407,845	38,612,286	51,689,623	34,253,181
S138	84,194,299	52,349,318	71,456,306	45,980,321
S139	93,517,820	59,817,478	79,676,653	52,896,894
S140	57,104,205	35,308,647	48,385,984	30,949,542
S141	75,644,026	43,799,045	62,906,034	37,430,049
S142	82,840,577	49,140,235	68,999,410	42,219,651
S143	59,043,693	37,248,134	50,325,472	32,889,029
S144	80,287,962	48,442,981	67,549,970	42,073,985
S145	88,390,768	54,690,425	74,549,600	47,769,841
S146 = geometric improvement alternative	17,848,062	10,346,017	14,847,244	8,845,608
MIN	52,422,662	30,627,103	43,704,441	25,384,932
MAX	244,977,085	173,717,448	215,504,695	158,981,253
MEAN	85,997,991			

L.3 BCR RESULTS PER ALTERNATIVE AND SCENARIO

Table L.4: BCR (with travel-cost benefits for year 1 only) for the bicycle-sharing and geometric improvement alternatives.

SCENARIO	BCR			
	with VOT 1	with VOT 2	with VOT 3	with VOT 4
S2	1.48	1.26	1.39	1.21
S3	1.20	1.08	1.15	1.05
S4	1.23	1.12	1.19	1.09
S5	1.66	1.41	1.56	1.36
S6	1.36	1.22	1.30	1.19
S7	1.40	1.27	1.34	1.24
S8	1.57	1.34	1.48	1.30
S9	1.29	1.16	1.24	1.14
S10	1.33	1.21	1.28	1.19
S11	1.75	1.50	1.65	1.45
S12	1.45	1.31	1.40	1.28
S13	1.50	1.37	1.45	1.34
S14	1.42	1.19	1.33	1.15
S15	1.13	1.01	1.08	0.98
S16	1.16	1.04	1.11	1.02
S17	1.59	1.33	1.49	1.28
S18	1.28	1.14	1.22	1.11
S19	1.31	1.18	1.26	1.15
S20	1.04	0.87	0.97	0.83
S21	0.92	0.82	0.88	0.80
S22	0.92	0.84	0.89	0.82
S23	1.16	0.97	1.09	0.93
S24	1.04	0.92	0.99	0.90
S25	1.04	0.95	1.00	0.93
S26	1.09	0.92	1.02	0.89
S27	0.98	0.88	0.94	0.86
S28	0.99	0.91	0.96	0.89
S29	1.22	1.03	1.15	0.99
S30	1.11	1.00	1.06	0.97
S31	1.12	1.03	1.08	1.01
S32	1.00	0.83	0.93	0.79
S33	0.87	0.77	0.83	0.75
S34	0.87	0.78	0.83	0.76
S35	1.12	0.92	1.04	0.89
S36	0.98	0.86	0.93	0.84
S37	0.98	0.88	0.94	0.86
S38	0.72	0.60	0.67	0.57
S39	0.64	0.56	0.61	0.55
S40	0.64	0.57	0.61	0.56
S41	0.81	0.67	0.75	0.64
S42	0.72	0.64	0.69	0.62
S43	0.72	0.65	0.69	0.63
S44	0.76	0.63	0.71	0.61
S45	0.68	0.61	0.65	0.59
S46	0.68	0.62	0.66	0.61
S47	0.85	0.71	0.79	0.68
S48	0.77	0.69	0.74	0.67
S49	0.78	0.70	0.74	0.69
S50	0.70	0.57	0.64	0.54
S51	0.61	0.53	0.58	0.51
S52	0.60	0.54	0.57	0.52
S53	0.78	0.64	0.72	0.61
S54	0.68	0.60	0.65	0.58
S55	0.68	0.61	0.65	0.59
S56	1.24	1.04	1.16	1.00
S57	1.10	0.98	1.05	0.96
S58	1.11	1.01	1.07	0.99
S59	1.39	1.16	1.30	1.11
S60	1.24	1.10	1.18	1.07
S61	1.26	1.14	1.21	1.12
S62	1.31	1.10	1.22	1.06
S63	1.18	1.06	1.13	1.03
S64	1.20	1.09	1.15	1.07
S65	1.46	1.23	1.37	1.18
S66	1.32	1.19	1.27	1.16
S67	1.35	1.23	1.30	1.21
S68	1.19	0.99	1.11	0.95
S69	1.04	0.92	0.99	0.89
S70	1.05	0.94	1.00	0.92
S71	1.33	1.10	1.24	1.06
S72	1.17	1.03	1.11	1.00
S73	1.18	1.06	1.13	1.04
S74	0.95	0.79	0.89	0.76
S75	0.85	0.75	0.81	0.73

S76	0.86	0.77	0.82	0.76
S77	1.07	0.89	0.99	0.85
S78	0.96	0.84	0.91	0.82
S79	0.97	0.87	0.93	0.85
S80	1.00	0.84	0.94	0.81
S81	0.91	0.81	0.87	0.79
S82	0.92	0.83	0.88	0.82
S83	1.12	0.94	1.05	0.90
S84	1.02	0.91	0.98	0.89
S85	1.04	0.94	1.00	0.92
S86	0.92	0.75	0.85	0.72
S87	0.80	0.70	0.76	0.68
S88	0.81	0.72	0.77	0.70
S89	1.02	0.84	0.95	0.81
S90	0.90	0.79	0.86	0.77
S91	0.91	0.81	0.87	0.79
S92	0.68	0.56	0.63	0.53
S93	0.60	0.52	0.57	0.51
S94	0.60	0.53	0.57	0.52
S95	0.76	0.62	0.70	0.59
S96	0.67	0.59	0.64	0.57
S97	0.68	0.60	0.65	0.59
S98	0.71	0.59	0.66	0.56
S99	0.64	0.56	0.61	0.55
S100	0.64	0.58	0.61	0.56
S101	0.79	0.66	0.74	0.63
S102	0.72	0.63	0.68	0.61
S103	0.72	0.65	0.69	0.63
S104	0.65	0.53	0.60	0.51
S105	0.57	0.49	0.54	0.48
S106	0.57	0.50	0.54	0.49
S107	0.73	0.59	0.67	0.56
S108	0.64	0.55	0.60	0.53
S109	0.64	0.56	0.61	0.55
S110	1.08	0.89	1.00	0.85
S111	0.96	0.84	0.91	0.82
S112	1.03	0.92	0.98	0.90
S113	1.20	0.99	1.12	0.95
S114	1.07	0.94	1.02	0.92
S115	1.15	1.04	1.10	1.01
S116	1.13	0.94	1.06	0.91
S117	1.02	0.91	0.98	0.89
S118	1.10	1.00	1.06	0.97
S119	1.26	1.05	1.18	1.01
S120	1.14	1.01	1.09	0.99
S121	1.24	1.12	1.19	1.09
S122	1.04	0.85	0.96	0.81
S123	0.91	0.79	0.86	0.77
S124	0.97	0.86	0.92	0.84
S125	1.15	0.95	1.07	0.90
S126	1.01	0.88	0.96	0.86
S127	1.09	0.97	1.04	0.94
S128	0.85	0.69	0.78	0.66
S129	0.75	0.65	0.71	0.63
S130	0.80	0.71	0.76	0.69
S131	0.94	0.77	0.87	0.74
S132	0.84	0.73	0.79	0.71
S133	0.90	0.80	0.86	0.78
S134	0.89	0.73	0.82	0.70
S135	0.80	0.70	0.76	0.68
S136	0.85	0.77	0.82	0.75
S137	0.99	0.82	0.92	0.78
S138	0.89	0.78	0.85	0.76
S139	0.96	0.86	0.92	0.84
S140	0.81	0.66	0.75	0.63
S141	0.71	0.61	0.67	0.60
S142	0.75	0.67	0.72	0.65
S143	0.91	0.74	0.84	0.70
S144	0.79	0.69	0.75	0.66
S145	0.85	0.75	0.81	0.73
S146 = geometric improvement alternative	0.65	0.44	0.57	0.39
MIN	0.57	0.49	0.54	0.48
MAX	1.75	1.50	1.65	1.45
MEAN	0.90			

Table L.5: BCR (with travel-cost benefits for year 1 multiplied by factor of 7.5) for the bicycle-sharing and geometric improvement alternatives.

SCENARIO	BCR			
	with VOT 1	with VOT 2	with VOT 3	with VOT 4
S2	6.31	4.63	5.64	4.29
S3	3.95	3.00	3.57	2.81
S4	3.79	2.92	3.43	2.74
S5	7.07	5.18	6.31	4.80
S6	4.46	3.38	4.03	3.17
S7	4.29	3.30	3.88	3.10
S8	6.39	4.71	5.72	4.37
S9	4.04	3.08	3.65	2.89
S10	3.88	3.01	3.52	2.83
S11	7.16	5.27	6.40	4.90
S12	4.55	3.48	4.12	3.26
S13	4.39	3.41	3.98	3.20
S14	6.24	4.56	5.57	4.22
S15	3.88	2.93	3.50	2.74
S16	3.71	2.84	3.35	2.66
S17	6.99	5.11	6.24	4.73
S18	4.38	3.30	3.95	3.09
S19	4.20	3.22	3.80	3.01
S20	4.70	3.42	4.19	3.16
S21	3.07	2.32	2.77	2.17
S22	2.80	2.16	2.53	2.02
S23	5.27	3.83	4.69	3.54
S24	3.46	2.61	3.12	2.44
S25	3.17	2.44	2.87	2.29
S26	4.76	3.47	4.24	3.22
S27	3.13	2.38	2.83	2.23
S28	2.87	2.22	2.60	2.09
S29	5.33	3.89	4.75	3.60
S30	3.54	2.69	3.20	2.52
S31	3.25	2.52	2.95	2.37
S32	4.66	3.38	4.15	3.12
S33	3.02	2.26	2.72	2.11
S34	2.74	2.10	2.48	1.97
S35	5.22	3.78	4.65	3.49
S36	3.40	2.55	3.06	2.39
S37	3.11	2.38	2.81	2.23
S38	3.37	2.43	2.99	2.24
S39	2.25	1.68	2.02	1.57
S40	2.04	1.55	1.84	1.45
S41	3.77	2.72	3.35	2.51
S42	2.54	1.90	2.28	1.77
S43	2.31	1.76	2.08	1.64
S44	3.40	2.46	3.03	2.27
S45	2.30	1.72	2.07	1.61
S46	2.09	1.60	1.89	1.50
S47	3.81	2.76	3.39	2.55
S48	2.59	1.94	2.33	1.82
S49	2.36	1.81	2.14	1.70
S50	3.34	2.40	2.96	2.21
S51	2.22	1.65	1.99	1.53
S52	2.00	1.51	1.80	1.41
S53	3.74	2.69	3.32	2.48
S54	2.50	1.86	2.25	1.73
S55	2.27	1.72	2.04	1.60
S56	5.62	4.09	5.01	3.78
S57	3.67	2.77	3.31	2.59
S58	3.38	2.60	3.06	2.44
S59	6.29	4.57	5.60	4.23
S60	4.13	3.12	3.72	2.91
S61	3.82	2.94	3.45	2.76
S62	5.69	4.15	5.07	3.85
S63	3.75	2.85	3.39	2.67
S64	3.47	2.69	3.14	2.53
S65	6.36	4.64	5.67	4.30
S66	4.22	3.20	3.81	3.00
S67	3.91	3.03	3.55	2.85
S68	5.57	4.04	4.96	3.73
S69	3.61	2.71	3.25	2.53
S70	3.32	2.54	2.99	2.38
S71	6.23	4.51	5.54	4.17
S72	4.06	3.05	3.65	2.84
S73	3.74	2.86	3.38	2.68
S74	4.39	3.18	3.91	2.93
S75	2.94	2.20	2.64	2.05

S76	2.69	2.05	2.43	1.92
S77	4.91	3.55	4.37	3.28
S78	3.30	2.47	2.97	2.31
S79	3.03	2.32	2.74	2.17
S80	4.44	3.22	3.95	2.98
S81	3.00	2.26	2.70	2.11
S82	2.75	2.12	2.49	1.99
S83	4.96	3.60	4.42	3.33
S84	3.37	2.54	3.04	2.37
S85	3.10	2.39	2.81	2.24
S86	4.35	3.14	3.87	2.90
S87	2.89	2.15	2.60	2.01
S88	2.64	2.00	2.38	1.87
S89	4.87	3.51	4.32	3.24
S90	3.25	2.42	2.92	2.25
S91	2.98	2.26	2.68	2.11
S92	3.24	2.32	2.87	2.13
S93	2.19	1.62	1.96	1.50
S94	2.01	1.51	1.80	1.41
S95	3.62	2.59	3.21	2.38
S96	2.46	1.82	2.20	1.69
S97	2.27	1.70	2.04	1.59
S98	3.27	2.35	2.90	2.17
S99	2.23	1.66	2.00	1.54
S100	2.05	1.55	1.85	1.45
S101	3.65	2.63	3.24	2.42
S102	2.50	1.86	2.25	1.73
S103	2.31	1.75	2.08	1.64
S104	3.21	2.29	2.84	2.11
S105	2.16	1.59	1.93	1.47
S106	1.98	1.48	1.77	1.38
S107	3.59	2.56	3.18	2.36
S108	2.43	1.78	2.17	1.65
S109	2.23	1.67	2.00	1.55
S110	5.02	3.62	4.46	3.34
S111	3.37	2.51	3.03	2.34
S112	3.28	2.50	2.96	2.33
S113	5.59	4.03	4.96	3.71
S114	3.77	2.81	3.38	2.62
S115	3.69	2.80	3.32	2.62
S116	5.07	3.67	4.51	3.39
S117	3.44	2.58	3.09	2.41
S118	3.36	2.57	3.03	2.41
S119	5.64	4.08	5.02	3.77
S120	3.84	2.88	3.45	2.69
S121	3.77	2.88	3.40	2.70
S122	4.97	3.57	4.41	3.29
S123	3.32	2.46	2.98	2.29
S124	3.22	2.44	2.90	2.27
S125	5.54	3.98	4.91	3.67
S126	3.71	2.75	3.32	2.56
S127	3.62	2.73	3.25	2.55
S128	4.03	2.89	3.58	2.66
S129	2.74	2.02	2.45	1.88
S130	2.67	2.01	2.40	1.88
S131	4.49	3.22	3.98	2.96
S132	3.06	2.26	2.74	2.10
S133	3.00	2.26	2.70	2.11
S134	4.07	2.93	3.62	2.70
S135	2.79	2.07	2.50	1.93
S136	2.73	2.07	2.46	1.93
S137	4.54	3.26	4.03	3.01
S138	3.11	2.31	2.79	2.15
S139	3.06	2.32	2.76	2.17
S140	4.00	2.86	3.54	2.63
S141	2.70	1.98	2.41	1.84
S142	2.63	1.97	2.36	1.83
S143	4.46	3.18	3.95	2.93
S144	3.01	2.21	2.69	2.05
S145	2.95	2.21	2.65	2.05
S146 = geometric improvement alternative	4.91	3.26	4.25	2.94
MIN	1.98	1.48	1.77	1.38
MAX	7.16	5.27	6.40	4.90
MEAN	3.08			